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09. PLANT PHYSIOLOGY

Unit 1: Cell Organelles and Water Relations

Cell organelles and their physiological functions; Structure and physiological functions of cell wall, cell inclusions. Cell membrane structure and functions. Water: Properties and function of water in cell; Soil and plant water relation: Concept of water potential, Plant and soil water potential and their components, SPAC, method to determine soil and plant water status; Mechanism of water uptake by roots, transport in roots and other tissues; Transpiration: Stomatal and non-stomatal water loss from plants, evaporation and transpiration, energy balance, plant and environmental factors affecting transpiration; Stomata: structure and function, Mechanism of stomatal movement, regulation of stomatal opening and closing by endogenous and environmental cues, antitranspirants. Water use efficiency (WUE): physiological basis, methods of measurement, improvement in WUE. Indices for assessment of drought resistance.

Unit 2: Metabolic Processes and Growth Regulation

Energy and work, free energy and chemical potential, redox reactions and electrochemical potential; Enzyme classification and mechanism of action, factors affecting enzyme action; Gene expression and protein turnover; Photosynthesis: Chloroplast- Structure and function; light reaction-cyclic, non-cyclic, psuedocyclic: Rubisco structure and regulations CO_2 diffusion mechanism; Photochemical processes- C_3, C_4 and CAM photosynthesis, Regulation of photosynthetic enzymes, Ecological aspects of C_4 and CAM; Photorespiration- significance and approaches to minimize it in C_3 plants; Sucrose, starch and polysaccharide metabolism; Phloem loading and transport of sugars; Source-sink relationship; Carbon isotope discrimination; Respiration: Mitochondria structure and function; Electron transport and ATP synthesis; Glycolysis, Krebs cycle, anaerobic respiration; Growth Respiration, Maintenance respiration, Apparent Respiration, Cyanide resistant respiration and its significance; Lipid metabolism: storage, structural and protective lipids; Secondary metabolites and their significance in the plant.

Unit 3: Crop Productivity and Modelling

Physiology of major cereals, pulses and oilseed crops. Role of crop physiology in agriculture;Growth models describing yield (Duncan/Passioura); Crop growth Analysis: LAI, NAR,CGR, LAD, RGR, SLA, SPW, HI; Canopy photosynthesis - leaf area and net assimilation rates as determining factors; Light interception, light extinction coefficient and canopy architecture; Light interception as a major function of leaf area-index; Biomass and yield relations; Assimilate partitioning; yield and yield structure analysis; Concept of source and sink; factors influencing source and sink size and productivity; Concept of optimum LAI. Environmental factors determining crop growth: Light, temperature and VPD, effect of photoperiod and thermos-period on duration of growth stages; Ideotype concept: selection- indices for improving crop productivity; Concept of Thermal time, heat unit, GDD in growth and development of crops; Analytical techniques and instrumentation in plant physiology.

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Unit 4: Abiotic Stress Responses in Plants

Abiotic stresses affecting plant productivity: Drought, water logging, extreme temperature, salinity, high and low light; Drought: Drought characteristic features, Development of water deficits, energy balance concept, transpiration and it's regulation -stomatal functions/ reponses to VPD. Physiological processes affected by drought; Drought resistancemechanisms: Escape, Dehydration avoidance, Dehydration tolerance; osmotic adjustments and Osmo protectants; Stress proteins-LEA, Dehydrins, etc; stomatal regulation for minimizing water loss; Water use efficiency and Passioura's model; Physiological and molecular mechanism to improve WUE; high and low temperature: physiological effect on plant, role of lipid membrane in tolerance of extreme temperature, HSPs and their function: high and low light stress: photo oxidation, photo inhibition, mechanism of tolerance, shade avoidance response; Salinity: effect on cellular and whole plant level, tolerance mechanism, SOS pathway; Heavy metal stress: Aluminum and Cadmium toxicity effect on plant and their tolerance mechanism, phytochelatins; Stress and hormones: ABA as signaling molecule, cytokinin as negative signal; Oxidative stress: ROS role and tolerance mechanism.

Unit 5: Plant Growth Regulators and Plant Development

Plant growth regulators: Hormones, endogenous growth substances and synthetic chemicals; Endogenous growth regulating substances other than hormones; Classification, site of synthesis, biosynthetic pathways and metabolism and influence on plant growth and development by auxins, gibberellins, cytokinins, abscisic acid and ethylene; Hormone signal perception, transduction-

Receptor components, signal transduction and mechanism of action of Auxin, Gibberellins, Cytokinin, ABS and ethylene: Action of hormones on cellular functions: Auxins-cell elongation, retardation of abscission of plant parts; gibberellins-stem elongation, germination of dormant seeds; cytokinin- cell division, retardation of senescence; Abscisic acid-stomatal closure and induction of drought resistance: ethylene-fruit ripening, acceleration of senescence of leaves; Hormone mutants; Interaction of hormones in theregulation of plant growth and development processes; Physiological and molecular aspects of regulation of growth and differentiation, rooting of cutting, Apical dominance, Flowering; role of hormone in fruit growth and development, Senescence, Abscission, induction and breaking of seed and bud dormancy; improving post-harvest life of fruits Synthetic growth regulators; Practical utility in agriculture and horticulture.

Unit 6: Mineral Nutrition

Importance of mineral nutrition in plant growth; Classification and essentiality criteria; Beneficial elements; factors affecting the nutrient availability; critical nutrient concentration; Mineral nutrient: function, deficiency symptoms/ disorders, toxicity and remedies; General mechanisms: concept of apparent free space and Donnan free space ; Mineral nutrient uptake and transport: membrane transport proteins - active transport, Primary and secondary transport- carriers and pumps; LATs and HATs; Short distance transport-pathway fromexternal solution (Apoplasm) to *sieve* across the root cortical cells, factors contributing to xylem loading; Long-distance transport in xylem and phloem, xylem unloading in leaf cells; Foliar nutrition: Uptake and release of mineral nutrients by foliage; Rhizosphere and root biology in relation to nutrient acquisition, influence of micro-organisms in nutrient acquisition, release and uptake by plant roots; Yield and mineral nutrition concept of nutrient use efficiency; Heavy metal toxicity and concept of phytoremediation; Physiological and molecular mechanism of nutrient use efficiency; Nitrogen metabolism; Inorganic nitrogen species (N2, N03, NH3) and their reduction, protein synthesis;. Sulphate uptake and reduction.

Unit 7: Climate and Climate Change

Climate change: definition, history and evidences: analytical methods to determine long term changes in environment-Tree ring, cellulose, stable carbon isotope discrimination, for hydrological changes; Climate change projections and its impact on crop and ecosystem; The greenhouse gases and global warning; CO2 as an important green-houses gas; Effect of elevated CO2 on plant growth and development; Methane as a greenhouse gas. Prediction on global warming; Effect of high temperature on plant growth and development; High temperature and CO2 interaction on plant growth and productivity; chlorofluorocarbon (CFC)-their impact on ozone layer: ozone hole and alteration in UV-B radiation; Technologies for climate change studies (FACE, TGT, OTC etc.) Approaches to improve adaptation to changing environment. Effects of UV-B radiation on plant ecosystem, repair and acclimation to UV-B damage; Carotenoids and their role in membrane stabilization; Air pollution, SO2, NO, methane, ozone, peroxyacetyl nitrate and their effect on the ecosystem. Industrial and domestic effluent their effect, on aquatic ecosystem, plant growth and development.

Unit 8: Seed Physiology

Structure of seeds and their storage; Seed development patterns and source of assimilates for seed development; Pathway of movement of assimilates in developing grains of monocots and dicots; Chemical composition of seeds; Storage of carbohydrates, proteins and fats in seeds; Seed germination: Hydration of seeds, Physiological processes, Seed respiration, mitochondrial activity, Mobilization of stored resource in seeds; Chemistry of oxidation of starch, proteins and fats; Utilization of breakdown products by embryonic axis; Controlprocesses in mobilization of stored reserves- Role of embryonic axes; Gibberellin and α- amylase and other hydrolytic activity; Seed maturation phase and desiccation damage- role ofLEA proteins; Seed viability; Seed dormancy; Means to overcome seed dormancy; Interaction of Gibberellin and ABA in regulation of seed germination and dormancy

Unit 9: Physiology of Flowering and Reproduction

Evolutionary history of flowering plants (angiosperms); Semelparous and iteroparous reproduction; monocarpic and perennial life; Flowering phenomenon; juvenility to flowering transition; Photoperiodic responses and the mechanisms in short and long day plants; Photoperiodism and its importance; Theories related to flowering; Gene expression and control of flowering; Thermoperiodism and its importance; Mechanism of vernalization; Photomorphogenesis, photoreceptors: phytochrome, cryptochrome, phototropins; Circadian rhythms: features and mechanism; Mating strategy in plants, molecular techniques to understand mating patterns, self-incompatibility responses, physiological processes mediating fertilization (pollen-stigma interactions) , seed and fruit development, seed and fruit abortion and means to overcome it.

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Molecular biology of seed development, physiological basis of cytoplasmic male sterility and fertility restoration. Physiology of heterosis.

Unit 10: Physiology of Horticultural and Plantation Crop species

Growth and development of horticultural and plantation crop species; Juvenility, shoot growth, types of shoots, patterns of shoot growth, cambial growth and its regulation; Physiological aspects of pruning and dwarfing; Growth measurements; Water relations oftree species. Water uptake and transport; Sexual and asexual propagation; Rootstock andscion interactions; Physiology of flowering in perennial species, photoperiodism and thermoperiodism; Physiological aspects of fruit crops: mango, banana, grapes, citrus, papaya and pineapple; Physiological aspects of plantation crops: tea, coffee, cardamom, coconut, andblack pepper.

Unit 11: Post-Harvest Physiology

Senescence and ageing in plants; Ethylene the senescence hormone; leaf senescence. Monocarpic plant senescence; Biochemistry and molecular biology of flower senescence; Gene expression during senescence; Concept of physiological maturity and harvestable maturity; Post harvest changes in biochemical constituents in field crops: loss of viability, loss of nutritive value: environmental factors influencing post-harvest deterioration of seeds; Physiological and biochemical changes during fruit ripening and storage; Senescence and post-harvest life of cut flowers; Physical, physiological and chemical control of post -harvest deterioration of fruits, vegetables and cut flowers and its significance during storage and transport; The molecular approach in the regulation of fruit ripening; Transgenic technology for improvement of shelf-life; Edible vaccine; Programmed cell death (PCD).

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Unit 12: Morphogenesis, Tissue Culture and Plant Transformation

Morphogenesis: the cellular basis of growth and morphogenesis; polarity in tip-growing cells and diffusive growing cells: Control of cell division and differentiation, phytochromes, different forms, physiological effects and gene regulation; cellular totipotency; physiologyand biochemistry of differentiation, in organ cell, tissue and cultures; micropropagationstrategies; application of tissue culture in agriculture, horticulture, forestry and industry; plant transformation; transformation vectors, concept of selectable and scorable markers; *Agrobacterium* mediated transformation, binary vectors, biolistics, Electroporation; Selection of putative transgenic plants: genetic analysis, PCR, Southern analysis evaluation of transgenic plants Genetic engineering and genome editing for trait improvement: Introductionto GMOs and its application in crop improvement, Agrobacterium and other methods of plant transformation; Genome editing techniques: CRISPR/Cas9, Zinc finger nucleases, TALENs, etc.

Unit 13: Phenome-Genome relationships

Next generation Phenotyping: Genome-phenome relationship, definition of phenotyping, GxE interaction on phenome; Phenotyping bottleneck in establishing Phenotype-genotype relationships; The concepts of "phene and trait. Concepts of Plants to sensors and sensors to plants.

CHAPTER 01
Cell Organelles and Water Relations

2021

1. Which of the following components is the predominant fibrillar structural polymer in the primary plant cell wall?
(A) Cellulose
(B) Hemicellulose
(C) Pectin
(D) Lignin

2016

2. Plasmodesmata are primarily responsible for which of the following cellular functions?
(A) Apoplastic transport of fluid
(B) Secondary wall lignification
(C) Symplastic communication
(D) Generation of turgor pressure

2007

3. Identify the correct statement regarding hemicellulose in the plant cell wall.
(A) It cross-links cellulose microfibrils as a tethering glycan.
(B) It forms the main rigid and crystalline microfibril matrix.
(C) It constitutes the primary component of the middle lamella.
(D) It acts as a hydrophobic barrier preventing cellular water loss.

2007

4. Which of the following INCORRECTLY describes the composition of the middle lamella?
(A) It is primarily composed of pectic polysaccharides.
(B) It requires calcium and magnesium to form salt bridges.
(C) It is the first layer formed during cell division.
(D) It is heavily lignified in newly formed primary tissues.

2002

5. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): The secondary cell wall is generally formed after the cell has ceased enlarging.
Reason (R): Secondary cell walls lack the expansin proteins and flexibility required for cell growth, often containing rigid lignin.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2025

6. In the context of cell wall architecture, which component restricts the porosity of the wall and provides compressive strength in woody tissues?
(A) Pectin
(B) Cellulose
(C) Lignin
(D) Callose

2012

7. Based on structural arrangement, into which category do homogalacturonan and rhamnogalacturonan fall?
(A) Cellulosic microfibrils
(B) Hemicellulosic tethers
(C) Structural cell wall proteins
(D) Pectic polysaccharides

2009

8. Comparing primary and secondary cell walls, which feature is uniquely characteristic of the secondary cell wall?
(A) Deposition in three distinct anisotropic layers (S1, S2, S3)
(B) Presence of cellulose microfibrils within the wall matrix
(C) High concentrations of unesterified pectic polysaccharides
(D) The significant reduction in hemicellulosic glycans

2011

9. Which of the following is NOT a structural feature associated with primary cell walls?
(A) Extensin proteins within the wall
(B) Pit membranes with extensive torus development
(C) Xyloglucans acting as cross-linking glycans

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(D) Cellulose microfibrils providing tensile strength

2012

10. Match the cell wall components in List-I with their primary physiological roles in List-II.
List I: (Components)
P. Cellulose
Q. Pectin
R. Lignin
S. Callose
List II: (Physiological roles)
1. Wound response and sealing plasmodesmata
2. Hydrophobicity and mechanical rigidity
3. Hydration and gel formation
4. Tensile strength scaffold
(A) P-4, Q-3, R-2, S-1
(B) P-3, Q-4, R-1, S-2
(C) P-4, Q-2, R-3, S-1
(D) P-1, Q-3, R-2, S-4

2023

11. The fluid mosaic model of the cell membrane emphasizes that proteins are embedded in a fluid lipid bilayer. Who proposed this foundational model?
(A) Singer and Nicolson
(B) Schleiden and Schwann
(C) Danielli and Davson
(D) Robertson

2018

12. A decrease in environmental temperature triggers which biochemical adjustment to maintain cell membrane fluidity?
(A) Increased proportion of saturated fatty acids in the bilayer
(B) Decreased synthesis of aquaporin water channels in membranes
(C) Increased proportion of unsaturated fatty acids in the bilayer
(D) Thickening of the polar phospholipid head groups of the lipids

2011

13. What is the primary advantage of aquaporins in the plant cell membrane compared to simple diffusion of water?
(A) Facilitating water transport against a strong potential gradient
(B) Simultaneous transport of mineral ions with water molecules
(C) Preventing the entry of excess water during flooded conditions
(D) Allowing rapid, regulated, and bidirectional bulk flow of water

2013

14. Which membrane transport proteins undergo conformational changes to transport specific solutes across the lipid bilayer?
(A) Channel proteins
(B) Aquaporins
(C) Carrier proteins
(D) Peripheral structural proteins

2012

15. Consider the following statements regarding membrane transport proteins.
I. Channel proteins primarily facilitate active transport.
II. Carrier proteins can mediate both active and passive transport.
III. Aquaporins are an example of channel proteins.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I

2005

16. In the context of lipid bilayer dynamics, flip-flop movement of phospholipids between leaflets is rare because:
(A) Hydrophobic tails exhibit strong mutual repulsion forces
(B) Peripheral proteins anchor the lipids permanently in place
(C) Membrane carbohydrates block the path of transverse diffusion
(D) It requires moving a hydrophilic head through a hydrophobic core

2002

17. Identify the correct statement regarding the selectivity of aquaporins.
(A) Narrow selectivity filters exclude protons to maintain gradients
(B) They are permeable to small uncharged solutes like urea molecules
(C) They allow passive transport of sodium and potassium ion species
(D) They are permanently open and cannot be gated by any signals

2023

18. Which of the following statements INCORRECTLY describes the plant cell plasma membrane?
(A) It contains sterols that modulate fluidity.

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(B) It maintains an electrical potential difference across the bilayer.
(C) It is entirely impermeable to gases like CO_2 and oxygen.
(D) It houses cellulose synthase complexes.

2015

19. Which molecule represents the most appropriate endogenous regulator of aquaporin gating during drought stress?
(A) Reactive oxygen species modifying cysteine residues
(B) Gibberellic acid molecules acting as secondary messengers
(C) Cytokinin hormones regulating the rate of cell division
(D) Soluble sugar molecules acting as physical channel plugs

2003

20. Select the correct sequence of events during carrier-mediated active transport.
(A) Solute binding, ATP hydrolysis, conformational change, solute release
(B) ATP hydrolysis, solute binding, solute release, conformational change
(C) Conformational change, ATP hydrolysis, solute release, solute binding
(D) Solute release, ATP hydrolysis, solute binding, conformational change

2001

21. Which organelle of the endomembrane system is primarily responsible for the biosynthesis of membrane lipids?
(A) Rough Endoplasmic Reticulum
(B) Smooth Endoplasmic Reticulum
(C) Golgi apparatus
(D) Central vacuole

2013

22. The tonoplast can be best defined as the biological membrane that bounds which cellular compartment?
(A) Chloroplast
(B) Nucleus
(C) Vacuole
(D) Peroxisome

2004

23. High accumulation of osmotically active solutes inside the vacuole directly results in which physiological effect?
(A) A significant reduction in cellular turgor pressure
(B) Plasmolysis of the cell due to external water loss
(C) Shrinkage of the tonoplast and internal compartment
(D) Water influx driving expansion and turgor maintenance

2003

24. A plant cell heavily engaged in synthesizing and secreting hemicellulose and pectin would show a highly developed proliferation of which organelle?
(A) Golgi bodies
(B) Mitochondria
(C) Smooth ER
(D) Glyoxysomes

2023

25. Consider the following statements concerning the endomembrane system.
I. The nuclear envelope is continuous with the rough ER.
II. Vacuoles lack any transport proteins in their tonoplast.
III. Golgi bodies are composed of stacked flattened cisternae.
IV. The endomembrane system includes mitochondria.
Which of the above statement(s) is/are incorrect?
(A) I and III
(B) II and IV
(C) I, II and IV
(D) II, III and IV

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2017

26. Identify the correct pair matching the endomembrane component to its physiological role.
(A) Rough ER - Synthesis of complex structural polysaccharides
(B) Tonoplast - Storage of calcium ions and secondary metabolites
(C) Golgi apparatus - Translation of diverse cytosolic proteins
(D) Smooth ER - Secretion of integral membrane protein complexes

2009

27. Identify the incorrect pair regarding cellular compartments.
(A) Nucleolus - Site of lipid synthesis
(B) Endoplasmic reticulum - Intracellular transport network
(C) Dictyosomes - Plant Golgi apparatus
(D) Vacuole - Degradation of cellular macromolecules

2008

28. Comparing the rough and smooth endoplasmic reticulum, which feature is exclusive to the rough ER?
(A) Active participation in cellular lipid metabolism
(B) Structure characterized by a tubular network
(C) Presence of attached ribosomes for protein synthesis
(D) Significant involvement in the storage of calcium

2004

29. Which of the following is NOT considered a functional component of the plant endomembrane system?
(A) Golgi apparatus
(B) Plasma membrane
(C) Endoplasmic reticulum
(D) Chloroplast

2021

30. Determine the correct order of the standard secretory pathway in a plant cell.
I. Secretory vesicle
II. Rough Endoplasmic Reticulum
III. Golgi apparatus
IV. Plasma membrane
(A) II, III, I, IV
(B) III, II, I, IV
(C) II, I, III, IV
(D) I, II, III, IV

2011

31. The tonoplast maintains acidic conditions inside the vacuole primarily through the action of which transport mechanism?
(A) Activation of passive proton-specific channels
(B) Activity of V-type H^+-ATPase and H^+-PPase
(C) Facilitation by specialized aquaporin proteins
(D) Use of standard sodium-potassium ionic pumps

2021

32. Chloroplasts are semi-autonomous organelles characterized by the presence of a complex internal membrane system known as:
(A) Cristae
(B) Cisternae
(C) Microbodies
(D) Thylakoids

2006

33. Identify the correct statement regarding mitochondrial physiology.
(A) Inner membranes contain the electron transport chain.
(B) They serve as the primary site of the Calvin cycle.
(C) They lack internal DNA and ribosomes.
(D) They store large quantities of starch grains internally.

2005

34. A plant subjected to high light intensity and low CO_2 levels would heavily rely on which organelle to process toxic byproducts of oxygenation?
(A) Glyoxysome
(B) Amyloplast
(C) Peroxisome
(D) Golgi body

2002

35. Consider the following statements regarding specialized organelles.
I. Mitochondria generate ATP via oxidative phosphorylation.
II. Chloroplasts generate ATP via photophosphorylation.
III. Glyoxysomes convert stored lipids into carbohydrates.
IV. Peroxisomes are involved in photorespiration.
V. Amyloplasts are highly active in lipid storage.
Which of the above statement(s) is/are correct?
(A) I, II, III and IV
(B) II, III, IV and V
(C) I, III, IV and V
(D) I, II, IV and V

2019

36. Which statement INCORRECTLY characterizes glyoxysomes?
(A) They are specialized peroxisomes found in oil-rich seeds.
(B) They contain enzymes for the beta-oxidation of fatty acids.
(C) They possess enzymes of the glyoxylate cycle.
(D) They are highly active in mature, photosynthesizing leaves.

2009

37. The coordinated process of photorespiration requires the sequential interaction of which three organelles?
(A) Chloroplast, Mitochondrion, Vacuole
(B) Chloroplast, Peroxisome, Mitochondrion
(C) Chloroplast, Glyoxysome, Nucleus
(D) Mitochondrion, Golgi body, Peroxisome

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2003

38. The synthesis of ATP in both chloroplasts and mitochondria is driven by the establishment of an electrochemical gradient. What constitutes this gradient?
(A) Accumulation of sodium ions
(B) Accumulation of electrons in the stroma/ matrix
(C) Accumulation of protons across a membrane
(D) Depletion of potassium ions

2022

39. Comparing mitochondria and chloroplasts, which structural feature is uniquely found in chloroplasts?
(A) Double boundary membrane
(B) Circular DNA
(C) ATP synthase complexes
(D) Grana stacks

2017

40. Specialized plastids responsible for the synthesis and storage of carotenoid pigments in flowers and fruits are classified as:
(A) Chromoplasts
(B) Elaioplasts
(C) Amyloplasts
(D) Proteinoplasts

2025

41. Which sequence best represents the metabolic logic of the glyoxylate cycle in germinating seeds?
(A) Carbohydrate to lipid conversion for efficient storage
(B) Lipid to carbohydrate conversion to fuel early growth
(C) Protein breakdown to release amino acids for photosynthesis
(D) Direct oxidation of lipids to generate massive heat amounts

2007

42. All of the following organelles contain their own genetic material EXCEPT:
(A) Mitochondria
(B) Peroxisomes
(C) Chloroplasts
(D) Proplastids

2018

43. Ergastic substances in plant cells are best defined as:
(A) Non-protoplasmic reserve or excretory products
(B) Active transport pumps within the plasma membrane
(C) Enzymes involved in the photosynthetic Calvin cycle
(D) Structural proteins belonging to the cytoskeleton

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2022

44. Identify the correct statement about raphides.
(A) They are composed of calcium carbonate.
(B) They function primarily as a starch storage mechanism.
(C) They are needle-like crystals of calcium oxalate.
(D) They are exclusively found in the cell wall.

2014

45. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): Cystoliths are common ergastic structures found in the epidermal cells of certain plants like Ficus.
Reason (R): Cystoliths are formed by the deposition of calcium carbonate on a cellulose stalk extending from the cell wall.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2019

46. Which of the following INCORRECTLY describes a reserve food material found in plants?
(A) Starch is stored as solid grains in amyloplasts.
(B) Inulin is a polymer of fructose stored in solution in roots of Asteraceae.
(C) Aleurone grains are specialized lipid storage droplets.
(D) Glycogen is generally absent in higher plant cells.

2004

47. Aleurone grains, commonly found in the endosperm of cereal grains, primarily store which type of macromolecule?
(A) Polysaccharides
(B) Proteins
(C) Triglycerides
(D) Nucleic acids

2006

48. Based on their origin and function, essential oils, nectar, and resins are classified physiologically as:
(A) Excretory ergastic substances

(B) Primary photosynthetic products
(C) Structural cell inclusions
(D) Secretory ergastic substances

2015

49. Which of the following is NOT classified as an ergastic substance?
(A) Ribosomes
(B) Tannins
(C) Cystoliths
(D) Alkaloids

2006

50. Comparing raphides and sphaeraphides (druses), what is the primary structural difference despite both being calcium oxalate?
(A) Raphides are soluble in water, whereas sphaeraphides are highly insoluble.
(B) Raphides are extracellular, whereas sphaeraphides are entirely intranuclear.
(C) Raphides are needle-like bundles, whereas sphaeraphides are star-shaped clusters.
(D) Raphides contain calcium, whereas sphaeraphides contain magnesium.

2018

51. The formation of concentric or eccentric layers in starch grains is a direct consequence of:
(A) Alternating periods of carbohydrate deposition
(B) Deposition of varying amounts of protein molecules
(C) Rapid crystallization of calcium carbonate minerals
(D) Significant degradation of the amyloplast membrane

2011

52. Essential oils produced by plants are typically stored in specialized structures to prevent cellular damage. These structures are often:
(A) Standard vacuoles of the internal mesophyll cells
(B) The internal matrix of the cellular mitochondria
(C) The aqueous stroma of the leaf chloroplasts
(D) Glandular trichomes or specialized secretory cavities

2022

53. The physical property of cohesion in water refers to:
(A) The attraction between water and various solid surfaces
(B) The mutual attractive force between water molecules
(C) The ability of water to dissolve a wide range of solutes
(D) The movement of water from high to low concentrations

2025

54. Identify the correct statement regarding hydrogen bonding in water.
(A) Strong covalent bonds within a single water molecule
(B) High electronegativity of hydrogen compared to oxygen
(C) Polar attractions between hydrogen and oxygen atoms
(D) Bonds occurring only when water is in the solid state

2016

55. Match the physico-chemical properties of water (List-I) with their biological significance (List-II).
List I: (Properties)
P. High specific heat
Q. High latent heat of vaporization
R. Cohesion
S. Adhesion
List II: (Significance)
1. Sustains the continuous water column in xylem
2. Prevents rapid temperature fluctuations in plant tissues
3. Provides cooling effect during transpiration
4. Helps water adhere to xylem vessel walls
(A) P-2, Q-3, R-1, S-4
(B) P-3, Q-2, R-4, S-1
(C) P-2, Q-1, R-3, S-4
(D) P-1, Q-4, R-2, S-3

2002

56. The unusually high specific heat capacity of water is primarily responsible for which physiological benefit in plants?
(A) Thermal buffering against rapid temperature changes
(B) Rapid acceleration of various enzymatic reactions
(C) Facilitation of solute transport across the tonoplast
(D) Immediate closing of stomata during severe heat stress

2001

57. The amount of energy required to convert one gram of liquid water to water vapor at constant temperature is known as:

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(A) Latent heat of fusion
(B) Latent heat of vaporization
(C) Specific heat capacity
(D) Thermal conductivity

2015

58. Without the property of adhesion, which critical process in xylem transport would most likely fail?
(A) The generation of hydrostatic root pressure
(B) Maintenance of water columns against gravity
(C) Active loading of sucrose into the phloem tissue
(D) The opening of stomata in the early morning

2011

59. Which of the following statements INCORRECTLY describes the physico-chemical nature of the water molecule?
(A) The H-O-H bond angle is exactly 180 degrees, making it linear.
(B) It is a highly polar molecule.
(C) It acts as an excellent solvent for ionic and polar substances.
(D) It exhibits high surface tension compared to most other liquids.

2011

60. Surface tension in water is vital for capillary action in soil micropores. This phenomenon is a direct result of:
(A) Simple repulsive forces between the hydrogen atoms
(B) The relatively low dielectric constant of water
(C) Unbalanced cohesive forces at the air-water interface
(D) Dissolution of soil minerals increasing water density

2004

61. Which property of water makes it the most appropriate medium for biochemical reactions in the plant cell?
(A) Its ability to remain solid at high temperatures
(B) Its relatively low specific heat capacity value
(C) Its high viscosity restricting molecular movement
(D) Its high dielectric constant facilitating ion separation

2007

62. All of the following anomalous properties of water are critical to biological systems EXCEPT:
(A) An unusually high latent heat of fusion
(B) Expansion upon freezing into solid ice
(C) Low boiling point compared to other hydrides
(D) High cohesiveness between water molecules

2018

63. The initial absorption of water by solid colloidal materials causing them to enormously increase in volume is defined as:
(A) Osmosis
(B) Imbibition
(C) Plasmolysis
(D) Active transport

2002

64. The maximum pressure that can be developed in a solution when it is separated from pure water by a semi-permeable membrane is termed:
(A) Turgor pressure
(B) Wall pressure
(C) Matric pressure
(D) Osmotic pressure

2004

65. Consider the following statements regarding plasmolysis.
I. Incipient plasmolysis occurs when turgor pressure is zero.
II. Plasmolysis is the swelling of a cell placed in a hypotonic solution.
III. Severe plasmolysis leads to the separation of the plasma membrane from the cell wall.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I and III
(C) II and III
(D) I

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2004

66. Identify the correct statement about cellular turgor pressure.
(A) Pressure exerted by the cell wall against the protoplast
(B) The concentration of starch molecules in the vacuole
(C) Hydrostatic pressure of vacuolar fluid against the wall
(D) The presence of a negative value in fully hydrated cells

2023

67. According to Fick's Law, the rate of diffusion of a solute across a cellular boundary is directly proportional to the:
(A) Concentration gradient of the solute

(B) Thickness of the boundary layer
(C) Molecular weight of the solute squared
(D) Viscosity of the solvent

2007

68. Comparing osmosis and simple diffusion, which defining characteristic is exclusive to osmosis?
(A) Movement from a region of high to low potential
(B) Independence from environmental temperature shifts
(C) Requirement of ATP energy for molecular movement
(D) Use of semi-permeable membranes for solvent flow

2008

69. If a plant tissue is placed in a solution and exactly 50% of the cells show slight separation of the plasma membrane from the corners of the cell wall, the tissue is said to be at:
(A) Full turgor
(B) Incipient plasmolysis
(C) Complete plasmolysis
(D) Deplasmolysis

2006

70. Identify the INCORRECT pair regarding fundamental water relations.
(A) Hypotonic solution - Induces endosmosis and turgor
(B) Hypertonic solution - Induces exosmosis and plasmolysis
(C) Isotonic solution - Induces rapid cellular bursting
(D) Semipermeable membrane - Allows solvent but restricts solute passage

2002

71. Which of the following factors does NOT significantly affect the rate of imbibition in seeds?
(A) Temperature
(B) Affinity between the imbibant and water
(C) Water potential gradient
(D) Concentration of atmospheric CO_2

2003

72. Depending on the shape of the retreating protoplast, plasmolysis can be classified into two distinct morphological types known as:
(A) Concave and convex
(B) Reversible and irreversible
(C) Isotonic and hypotonic
(D) Symplastic and apoplastic

2007

73. In a fully turgid cell, the mechanical force exerted by the rigid cell wall to counterbalance turgor pressure is known as:
(A) Osmotic pressure
(B) Wall pressure
(C) Matric potential
(D) Suction pressure

2002

74. Water potential (Ψ_w) is best defined thermodynamically as the:
(A) The total volume of water stored in a cell
(B) Potential relative to pure water at standard STP
(C) Absolute kinetic energy of the water molecules
(D) Concentration of dissolved solutes in a vacuole

2024

75. Consider the following statements regarding the components of water potential.
I. Solute potential (Ψ_s) is always positive in plant cells.
II. Pressure potential (Ψ_p) can be positive, negative, or zero.
III. Matric potential (Ψ_m) is highly significant in fully vacuolated mature plant cells.
IV. Gravitational potential (Ψ_g) is generally negligible at the cellular level.
Which of the above statement(s) is/are incorrect?
(A) I and III
(B) II and IV
(C) I, II and III
(D) II, III and IV

2023

76. Identify the correct statement regarding solute potential (Ψ_s).
(A) It increases as the solute concentration increases.
(B) It is entirely independent of environmental heat.
(C) It is equal to osmotic pressure but with a negative sign.
(D) It determines the direction of water flow in the xylem.

2004

77. In the xylem vessels of a rapidly transpiring tree, the pressure potential (Ψ_p) is typically:
(A) Highly positive
(B) Zero
(C) Equal to the solute potential
(D) Negative (under tension)

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2007

78. Matric potential (Ψ_m) represents the reduction in free energy of water due to its interaction with:
(A) Presence of various dissolved salts
(B) Influence of the gravitational pull
(C) Interaction with solid cellular surfaces
(D) Variation in the atmospheric pressure

2019

79. The addition of non-volatile solutes to pure water directly causes:
(A) A significant increase in the water potential
(B) A decrease in potential due to lowered solute levels
(C) An immediate increase in the pressure potential
(D) No change in the thermodynamic free energy state

2024

80. A plant cell has a solute potential of -0.8 MPa and a pressure potential of 0.3 MPa. What is its water potential?
(A) -1.1 MPa
(B) -0.5 MPa
(C) 0.5 MPa
(D) 1.1 MPa

2003

81. Which statement INCORRECTLY characterizes the gravitational potential (Ψ_g) in plant water relations?
(A) It is the dominant force driving water uptake in root hairs.
(B) It depends on the height of water above the reference state.
(C) It depends on the density of water and acceleration of gravity.
(D) It becomes a significant factor only in very tall forest trees.

2009

82. What is the most widely accepted SI unit for measuring water potential in plant physiology?
(A) Atmospheres (atm)
(B) Bars
(C) Megapascals (MPa)
(D) Millimeters of mercury (mmHg)

2010

83. Comparing pure water and a 1M sucrose solution at standard temperature and pressure, pure water possesses:
(A) The maximum water potential, defined as zero
(B) A significantly lower cellular water potential
(C) A highly negative internal solute potential value
(D) Superior osmotic pressure within the solution

2018

84. The standard equation for cellular water potential is $\Psi_w = \Psi_s + \Psi_p + \Psi_m + \Psi_g$. In a typical mature parenchyma cell, which component is usually omitted from calculations due to its negligible contribution?
(A) Solute potential
(B) Pressure potential
(C) Matric potential
(D) Both matric and gravitational potentials

2004

85. Consider the following statements regarding soil water classification.
I. Gravitational water drains freely under the influence of gravity.
II. Capillary water is held in micropores and is highly available to plants.
III. Hygroscopic water forms a tightly bound film around soil particles.
IV. Field capacity is measured immediately during heavy rainfall.
V. The permanent wilting point represents the state where plants cannot recover turgor.
Which of the above statement(s) is/are correct?
(A) I, II, III and V
(B) II, III, IV and V
(C) I, II, IV and V
(D) I, III, IV and V

2025

86. Field capacity is physiologically defined as the water content of soil:
(A) When all pore spaces are filled with water.
(B) When the plant shows signs of irreversible wilting.
(C) After excess water has drained by gravity.
(D) That is held at a matric potential of -1.5 MPa.

NODIA

2022

87. Identify the correct statement regarding the Permanent Wilting Point (PWP).
(A) It is the moisture level at which plants grow most optimally.
(B) Plants can recover from PWP if placed overnight in a dark, humid environment without watering.
(C) It corresponds to the complete physical absence of water in the soil.

(D) It is typically reached when soil water potential falls to approximately -1.5 MPa.

2019

88. Which specific category of soil water constitutes the primary source of water utilized by root systems?
(A) Capillary water
(B) Gravitational water
(C) Hygroscopic water
(D) Chemically combined water

2025

89. Comparing hygroscopic and gravitational water, which thermodynamic feature dictates their non-availability to plants?
(A) Hygroscopic water drains too quickly; gravitational water is bound at highly negative potentials.
(B) Hygroscopic water is held at highly negative potentials; gravitational water drains too quickly.
(C) Both are held at potentials exceeding -15 MPa.
(D) Both are completely frozen at typical soil temperatures.

2019

90. A sandy soil typically holds less plant-available water than a clay loam because:
(A) Sand has a much higher specific surface area than clay.
(B) Sand consists of macropores allowing rapid drainage.
(C) Sand completely lacks any form of hygroscopic water.
(D) Sand chemically repels all available water molecules.

2003

91. The amount of "Available Water" in a soil profile is mathematically calculated as the difference in water content between which two constants?
(A) Field capacity and permanent wilting point
(B) Saturation capacity and field capacity
(C) Permanent wilting point and hygroscopic coefficient
(D) Gravitational water and capillary water

2025

92. Which of the following statements INCORRECTLY describes a soil moisture constant?
(A) Field capacity usually occurs at a soil matric potential of -0.01 to -0.03 MPa.
(B) Hygroscopic coefficient is measured when soil is in equilibrium with an atmosphere of 98% relative humidity.
(C) Permanent wilting point is identical for all plant species regardless of their drought tolerance.
(D) Saturation capacity represents the complete filling of both macro and micro pores.

2017

93. Which component of soil moisture is bound tightly to soil colloids with forces exceeding -31 MPa, making it utterly inaccessible to plants?
(A) Gravitational water
(B) Capillary water
(C) Field capacity water
(D) Hygroscopic water

NODIA

2008

94. At the permanent wilting point, the matric potential of typical agricultural soils is generally accepted to be around:
(A) 0 MPa
(B) -0.03 MPa
(C) -1.5 MPa
(D) -15 MPa

2017

95. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): The pressure chamber (Scholander bomb) is widely used to measure the water potential of excised leaves or shoots.
Reason (R): It directly measures the solute potential by extracting cell sap and evaluating its freezing point depression.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2021

96. Relative Water Content (RWC) is defined as a physiological metric that evaluates:
(A) The absolute volume of water transpired per day.
(B) The ratio of internal water to external moisture.
(C) The difference between tissue wet and dry weight.
(D) Water content relative to that at full turgor.

2017

97. Identify the correct principle underlying thermocouple psychrometry for measuring water potential.
(A) Measuring vapor pressure equilibrium with air.
(B) Measuring xylem tension using a gas-filled chamber.
(C) Using electrical conductivity of tissue homogenate.
(D) Crushing the leaf to measure osmotic pressure.

2013

98. An agronomist installing soil tensiometers to schedule irrigation must be aware that tensiometers generally fail to operate accurately at soil matric potentials lower than:
(A) 0 MPa
(B) -1.5 MPa
(C) -0.08 MPa due to column cavitation
(D) -15 MPa

2018

99. The formula to calculate Relative Water Content (RWC) requires which three mass measurements?
(A) Fresh mass, turgid mass, and dry mass
(B) Fresh mass, transpired mass, and dry mass
(C) Dry mass, ash mass, and turgid mass
(D) Fresh mass, saturated mass, and osmotic mass

2017

100. Identify the INCORRECT pair of measurement methodology and its target parameter.
(A) Pressure chamber - Leaf water potential
(B) Thermocouple psychrometer - Solute potential and tissue water potential
(C) Soil tensiometer - Soil matric potential
(D) Porometer - Soil moisture content

2025

101. Comparing the pressure chamber and the thermocouple psychrometer, which characteristic is true?
(A) Chamber is laboratory-restricted; psychrometry is field-portable.
(B) Chamber estimates xylem tension; psychrometer measures vapor.
(C) Both methods exclusively measure tissue osmotic potential.
(D) Psychrometry requires massive samples compared to the chamber.

2005

102. When using a pressure chamber, if the pressure applied exceeds the actual tension previously existing in the xylem, what physical event occurs?
(A) The leaf shrivels and instantly dries out.
(B) The cell walls undergo irreversible plastic deformation.
(C) Sap is forced back out of the cut surface.
(D) The sample undergoes spontaneous combustion.

2006

103. Which of the following tools is NOT utilized for determining the water status (potential or content) of plant tissues?
(A) Pressure bomb
(B) Thermocouple psychrometer
(C) Gravimetric RWC analysis
(D) Chlorophyll fluorometer

2016

104. Which time of day provides the most appropriate measurement of "predawn leaf water potential," serving as a reliable proxy for soil water status?
(A) Just before sunrise when potentials equilibrate.
(B) Solar noon when transpiration is maximized.
(C) Late afternoon when the VPD is at its highest.
(D) Midnight during peak plant respiratory activity.

2003

105. Match the pathways of water uptake in List-I with their anatomical descriptions in List-II.
List I: (Pathways)
P. Apoplastic pathway
Q. Symplastic pathway
R. Transmembrane pathway
S. Casparian strip
List II: (Descriptions)
1. Movement across cell membranes and vacuoles
2. Suberized barrier in the endodermis
3. Movement through intercellular spaces and cell walls
4. Movement through plasmodesmata
(A) P-3, Q-4, R-1, S-2
(B) P-4, Q-3, R-2, S-1
(C) P-1, Q-2, R-3, S-4
(D) P-3, Q-1, R-4, S-2

2021

106. The apoplast pathway of water movement refers to the continuous system formed by:

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(A) Interconnected vacuolar networks within cells.
(B) Cell walls, intercellular spaces, and xylem vessels.
(C) Plasmodesmatal connections between protoplasts.
(D) The fluid interior of the various chloroplasts.

2021

107. Identify the correct statement regarding the symplastic pathway.
(A) Water must cross the plasma membrane at least once.
(B) It offers the least resistance to flow in the cortex.
(C) It bypasses the living cytoplasm and organelles.
(D) It is completely blocked by the Casparian strip.

2014

108. The physiological function of the Casparian strip in the root endodermis is to:
(A) Accelerating the apoplastic flow of water.
(B) Preventing symplastic transport of nutrients.
(C) Forcing apoplastic water to cross a membrane.
(D) Storing large quantities of starch for growth.

2004

109. In the transmembrane pathway, water moves between cells by sequential crossing of:
(A) Only the primary cell walls of the cortex.
(B) Two plasma membranes and the cell wall.
(C) Plasmodesmata without contacting membranes.
(D) The tonoplast membrane of the vacuole only.

2004

110. Because of the suberin deposition in the radial and transverse walls of the endodermis, which consequence inevitably occurs during root water uptake?
(A) Water is actively pumped backwards into the soil.
(B) The symplast of the root completely disintegrates.
(C) The apoplastic continuum is broken at the stele.
(D) Root pressure drops to zero immediately.

2003

111. Comparing the resistance to water flow in the root cortex, which pathway generally exhibits the lowest hydraulic resistance under normal transpiring conditions?
(A) Transmembrane pathway
(B) Apoplastic pathway
(C) Symplastic pathway
(D) Vacuolar pathway

2017

112. Identify the INCORRECT statement regarding root anatomy and water absorption.
(A) Root hairs are unicellular extensions of the epiblema (epidermis).
(B) The xylem vessels in the root possess functional Casparian strips.
(C) The primary site of water absorption is the zone of maturation where root hairs are present.
(D) The exodermis, when present, can possess a suberized band similar to the endodermis.

2003

113. Which of the following pathways does NOT involve water crossing a plasma membrane at any point prior to reaching the endodermis?
(A) Symplastic pathway
(B) Transmembrane pathway
(C) Vacuolar pathway
(D) Apoplastic pathway

NODIA

2018

114. The deposition of suberin in the endodermis not only prevents uncontrolled apoplastic influx but also plays a critical role in preventing:
(A) Leakage of accumulated ions out of the stele.
(B) The synthesis of xylem sap proteins in roots.
(C) Entry of mycorrhizal fungi into the root hairs.
(D) The outward diffusion of oxygen to the soil.

2010

115. Consider the following statements regarding water uptake.
I. Root pressure contributes significantly to water ascent in tall trees.
II. Water moves from a region of higher water potential in the soil to a lower potential in the root.
III. Aquaporins facilitate water movement across the plasma membrane.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I, II and III

2013

116. The cohesion-tension theory, proposed by Dixon and Joly, explains the ascent of sap through:

(A) Continuous osmotic pumping of root cells.
(B) Capillary rise mediated by wall adhesion.
(C) Negative pressure pulling cohesive water.
(D) Pulsatory activity of xylem parenchyma cells.

2009

117. Root pressure is a positive hydrostatic pressure developed in the root xylem primarily due to:
(A) Active ion accumulation lowering xylem potential.
(B) Active secretion of water into the vessels.
(C) Rapid transpiration rates pulling water up.
(D) Expansion of the root due to secondary growth.

2017

118. Hydraulic lift is a phenomenon where deep-rooted plants pull water from deep moist soil layers and release it into shallower, dry layers. This typically occurs:
(A) At night when stomata are closed and flow is low.
(B) During peak midday transpiration in full light.
(C) Only during severe drought-induced leaf wilting.
(D) Continuously throughout the 24-hour cycle.

2021

119. Cavitation in xylem vessels leads to a drastic reduction in hydraulic conductivity. What is the physical cause of cavitation?
(A) Sap freezing or column tension breaking.
(B) Accumulation of starch in the xylem vessels.
(C) Excessive positive root pressure at night.
(D) Blockage of the vessels by fungal hyphae.

2017

120. Identify the correct statement regarding embolism recovery in plants.
(A) Embolisms can never be repaired once formed.
(B) Cavitated vessels immediately shed their walls.
(C) Plants secrete ABA to dissolve the air bubbles.
(D) Root pressure can dissolve bubbles and refill.

2007

121. Guttation, the exudation of xylem sap as droplets on the edges of leaves, is a direct visual manifestation of:
(A) Excessive transpiration of leaf water.
(B) Severe cavitation events in the xylem.
(C) Active phloem loading in source leaves.
(D) High root pressure and low transpiration.

2018

122. Identify the INCORRECT statement regarding the mechanisms of ascent of sap.
(A) Capillarity alone is insufficient to raise water to the tops of tall trees.
(B) The tensile strength of water is high enough to withstand significant tension without breaking.
(C) Atmospheric pressure pushing water from below is the primary driving force for sap ascent.
(D) Water forms a continuous column from the root to the leaf mesophyll.

2011

123. Comparing tracheids and vessel elements in terms of vulnerability to cavitation, which is generally true?
(A) Vessel elements are wider and more vulnerable.
(B) Tracheids are more vulnerable due to pit absence.
(C) Both are equally vulnerable due to diameters.
(D) Tracheids cavitate daily; vessels never do.

2017

124. All of the following factors contribute to the driving force or maintenance of the xylem sap column EXCEPT:
(A) Cohesive properties of water molecules.
(B) Transpirational pull from the leaves.
(C) Adhesive forces between water and lignin.
(D) Active water transport by xylem parenchyma.

2018

125. Consider the following statements regarding the cohesion-tension mechanism.
I. The driving force is the highly negative water potential of the atmosphere.
II. Water columns are maintained in a state of compression.
III. Xylem vessels must possess thick secondary walls to prevent inward collapse.
IV. The diameter of a tree trunk slightly shrinks during peak transpiration.
Which of the above statement(s) is/are incorrect?
(A) I and III
(B) II and IV
(C) Only II
(D) III and IV

2023

126. The cohesion-tension theory relies on the remarkable tensile strength of water. Which

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structural adaptation prevents air from being sucked into adjacent functional vessels from a cavitated one?
(A) The endodermal Casparian strip.
(B) The waxy cuticle on the leaf surface.
(C) Microcapillary pores in pit membranes.
(D) The vacuolar tonoplast membrane.

2016

127. The Soil-Plant-Atmosphere Continuum (SPAC) concept models water movement through the environment based on an analog to:
(A) An electrical circuit with various potentials.
(B) A purely chemical reaction cascade in cells.
(C) A quantum mechanical probability wave.
(D) A hydraulic dam system with active pumps.

2007

128. Identify the correct representation of the water potential gradient driving flow in the SPAC.
(A) $\Psi_{soil} > \Psi_{root} > \Psi_{leaf} > \Psi_{atmosphere}$
(B) $\Psi_{soil} < \Psi_{root} < \Psi_{leaf} < \Psi_{atmosphere}$
(C) $\Psi_{atmosphere} > \Psi_{leaf} > \Psi_{root} > \Psi_{soil}$
(D) $\Psi_{root} > \Psi_{soil} > \Psi_{atmosphere} > \Psi_{leaf}$

2019

129. In the SPAC circuit, a sudden increase in stomatal resistance will have what immediate effect on the system?
(A) A dramatic increase in transpirational flux.
(B) A decrease in leaf water potential values.
(C) Transpiration reduction and water conservation.
(D) Immediate cavitation of all root xylem.

2022

130. Hydraulic conductance is the reciprocal of hydraulic resistance. A plant adapting to a dry environment would likely modify its architecture to:
(A) Maximize hydraulic conductance infinitely.
(B) Decrease root hydraulic resistance to zero.
(C) Regulate stomata to prevent pressure drops.
(D) Increase conductance by shedding the cuticle.

2012

131. In dry soils, the primary resistance to water movement into the plant typically shifts from the root internal pathways to the:
(A) Resistance within the xylem vessels.
(B) Resistance of the leaf mesophyll.
(C) The soil-root interface and contact loss.
(D) The stomatal pores of the leaf.

2011

132. Identify the INCORRECT pair regarding resistance components in the SPAC.
(A) Boundary layer resistance - Dependent on wind.
(B) Stomatal resistance - Modulated by cell turgor.
(C) Xylem resistance - Variable based on pumps.
(D) Cuticular resistance - Generally constant.

2004

133. Which parameter is NOT considered a part of the driving force or resistance in the SPAC model?
(A) Vapor pressure deficit of the air
(B) Soil matric potential
(C) Xylem conduit diameter
(D) Phloem sucrose concentration

2008

134. Because the transition from the liquid phase in the leaf to the vapor phase in the air involves a massive drop in water potential, which resistance point overwhelmingly dominates the control of water loss?
(A) Root cortical resistance to flow.
(B) Xylem resistance to water ascent.
(C) Stomatal and boundary layer resistance.
(D) Soil bulk resistance to movement.

NODIA

2008

135. Consider the following typical water potential values representing the SPAC on a clear, sunny day.
I. Soil: -0.1 MPa
II. Root: -0.5 MPa
III. Leaf: -1.5 MPa
IV. Atmosphere: -100 MPa
V. Atmosphere: 0 MPa
Which of the above statement(s) is/are correct?
(A) I, II, III and IV
(B) I, II, III and V
(C) II, III, IV and V
(D) I, III, IV and V

2013

136. Comparing the liquid-phase and vapor-phase transport within the SPAC, flow in the vapor phase (from leaf to atmosphere) is primarily driven by gradients of:
(A) Hydrostatic pressure gradients.
(B) Osmotic potential differences.
(C) Water vapor concentration gradients.
(D) Gravitational potential forces.

2019

137. Transpiration is physiologically defined as the:
(A) Active secretion of liquid water from hydathodes.
(B) Loss of water vapor from the aerial plant parts.
(C) Movement of water from endodermis into xylem.
(D) Condensation of moisture onto the leaf surfaces.

2014

138. Which transpirational pathway typically accounts for 85-90% of total water loss in a healthy mesophytic leaf?
(A) Cuticular transpiration
(B) Lenticular transpiration
(C) Stomatal transpiration
(D) Bark transpiration

2007

139. Lenticular transpiration occurs through small openings in the corky tissues of woody stems and branches. Though minor in total volume, why is it physiologically relevant?
(A) It is the primary cooling mechanism for stems.
(B) It actively pumps water utilizing cellular ATP.
(C) It replaces leaf transpiration in the summer.
(D) It continues even when stomata are fully closed.

2010

140. Identify the correct statement regarding the leaf energy balance equation.
(A) Transpiration contributes a net heat gain.
(B) Latent heat loss dissipates solar radiation.
(C) Convective heat transfer is always to air.
(D) Metabolic heat is the largest budget component.

2015

141. The fundamental physical difference between evaporation from a free water surface and transpiration from a leaf is that transpiration:
(A) Does not require the latent heat of vaporization.
(B) Is subject to biological regulation via stomata.
(C) Is purely a physical process devoid of regulation.
(D) Occurs at a faster rate than free evaporation.

2014

142. If a broadleaf plant is exposed to full sunlight but its stomata are artificially forced closed, the most immediate physical consequence will be:
(A) A rapid drop in the leaf temperature.
(B) An increase in the photosynthetic rate.
(C) A significant increase in leaf temperature.
(D) The bursting of the epidermal cells.

2005

143. Identify the INCORRECT statement regarding cuticular transpiration.
(A) It involves water diffusing directly through the epidermal cuticle.
(B) It can account for a larger percentage of total transpiration in young leaves with thin cuticles.
(C) Waxes embedded in the cutin matrix significantly increase resistance to cuticular water loss.
(D) Its rate is under tight physiological control by specialized cuticular guard cells.

2019

144. Comparing stomatal and cuticular transpiration during night-time hours in a well-watered C3 plant, which pattern is generally observed?
(A) Both cease entirely at night.
(B) Stomatal transpiration dominates.
(C) Cuticular transpiration dominates.
(D) Stomata open widely for gas flow.

2010

145. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): The phase change of water from liquid to vapor inside the substomatal cavity requires a substantial input of energy.
Reason (R): The latent heat of vaporization of water is high, causing energy to be absorbed from the leaf tissue, thereby cooling it.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2025

146. All of the following are recognized natural pathways for transpirational water loss from a plant EXCEPT:
(A) Stomata
(B) Lenticels
(C) Cuticle

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(D) Casparian strip

2001

147. Which term in the leaf energy budget represents the energy dissipated when liquid water vaporizes during transpiration?
(A) Sensible heat (H)
(B) Latent heat (λE)
(C) Net radiation (R_n)
(D) Soil heat flux (G)

2012

148. In typical dicotyledonous plants, the morphological shape of the guard cells is:
(A) Dumbbell-shaped
(B) perfectly spherical
(C) Elongated and rectangular
(D) Kidney-shaped (reniform)

2008

149. Subsidiary cells, often found adjacent to guard cells, function primarily to:
(A) Provide a reservoir of ions for movements.
(B) Perform the bulk of leaf photosynthesis.
(C) Synthesize the waxy cuticle of the leaf.
(D) Block the stomatal pore during drought.

2014

150. Identify the correct statement regarding the microfibril arrangement in guard cell walls.
(A) Microfibrils are arranged longitudinally.
(B) They are arranged in a random pattern.
(C) Microfibrils are entirely absent in cells.
(D) Radial micellation causes cell elongation.

2003

151. Grasses and many other monocots possess highly specialized stomata. The unique feature of their guard cells is that they are:
(A) Dumbbell-shaped with bulbous, thin ends.
(B) Kidney-shaped with uniformly thick walls.
(C) Completely lacking chloroplasts in cells.
(D) Fused permanently to the subsidiary cells.

2009

152. Because the ventral (inner) wall of the dicot guard cell facing the pore is thicker and less elastic than the dorsal (outer) wall, an increase in turgor pressure causes the guard cell to:
(A) Swell inward, closing the pore.
(B) Burst open due to high pressure.
(C) Curve outward, opening the pore.
(D) Shrink dramatically in the leaf.

2008

153. Identify the INCORRECT statement regarding stomatal distribution on leaves.
(A) Epistomatic leaves have upper stomata.
(B) Many trees have hypostomatic leaves.
(C) Amphistomatic leaves have both surfaces.
(D) Hypostomatic leaves are in aquatic plants.

2022

154. Amphistomatic leaves, which facilitate high rates of gas exchange, are most commonly found in which group of plants?
(A) Submerged aquatic species.
(B) Grasses and crops like maize.
(C) Shade-adapted understory ferns.
(D) Coniferous needles exclusively.

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2006

155. Match the stomatal distribution types in List-I with their characteristic plant examples in List-II.
List I: (Types)
P. Apple type (Hypostomatic)
Q. Potato type (Amphistomatic, more on lower)
R. Oat type (Amphistomatic, equal distribution)
S. Water lily type (Epistomatic)
List II: (Characteristics)
1. Stomata on both surfaces equally
2. Stomata only on lower surface
3. Stomata only on upper surface
4. Stomata on both, but more on lower
(A) P-2, Q-4, R-1, S-3
(B) P-3, Q-1, R-4, S-2
(C) P-4, Q-2, R-3, S-1
(D) P-1, Q-3, R-2, S-4

2014

156. Comparing monocot (dumbbell) and dicot (kidney) guard cells, which physiological feature do they share despite their morphological differences?
(A) Reliance on specialized subsidiary cells.
(B) Requirement of radial micellation for opening.
(C) An absence of mitochondria.
(D) Opening by shrinking their total volume.

2004

157. Which of the following is NOT a characteristic feature of functional guard cells?
(A) Presence of chloroplasts
(B) Differential thickening of cell walls
(C) Absence of mitochondria
(D) Radial orientation of cellulose microfibrils

2010

158. The opening of the stomatal pore is directly driven by an increase in:
(A) Guard cell turgor pressure

(B) Epidermal cell turgor pressure
(C) Guard cell wall pressure
(D) Guard cell matric potential

2024

159. The active potassium-ion (K^+) pump hypothesis for stomatal opening was most notably elaborated by:
(A) Sayre and Scarth
(B) Levitt and Fujino
(C) Calvin and Benson
(D) Dixon and Joly

2019

160. Identify the correct statement regarding the role of malate during stomatal opening.
(A) Malate balances the influx of K^+ ions.
(B) Malate is exported to lower internal pressure.
(C) Malate binds to cellulose to weaken the wall.
(D) Malate acts as an inhibitor of the proton pump.

2012

161. According to the starch-sugar interconversion theory, a high pH in the guard cells during the day (due to photosynthesis reducing CO_2) leads to:
(A) Starch to sugar conversion opens stomata.
(B) Sugar to starch conversion closes stomata.
(C) Immediate degradation of leaf chlorophyll.
(D) Pumping of protons into the vacuole.

2004

162. The primary active transport event initiating stomatal opening is the:
(A) Influx of calcium ions into the vacuole.
(B) Active pumping of water by aquaporins.
(C) Secretion of ABA into the leaf apoplast.
(D) Proton efflux via plasma membrane ATPase.

2021

163. Inhibitors of ATP synthesis, such as uncouplers of oxidative phosphorylation, prevent stomatal opening in the light. This demonstrates that:
(A) Stomatal opening is a purely passive process.
(B) The proton pump requires a supply of ATP.
(C) Guard cells lack functional mitochondria.
(D) ATP acts as a structural pore component.

2011

164. Identify the INCORRECT statement regarding the mechanics of stomatal opening.
(A) Chloride (Cl^-) ions often enter the guard cell along with K^+ to maintain electrical neutrality.
(B) The water potential of the guard cell drops heavily during opening.
(C) Photophosphorylation and oxidative phosphorylation both contribute ATP for the process.
(D) Water enters the guard cells exosmotically from the subsidiary cells.

2013

165. Select the correct sequence of events leading to stomatal opening from the given options.
(A) H^+ efflux → Hyperpolarization → K^+ influx → Decrease in Ψ_s → Water influx → Increased turgor
(B) K^+ influx → H^+ efflux → Increase in Ψ_s → Water efflux → Increased turgor
(C) Water influx → Increased turgor → H^+ efflux → K^+ influx → Decrease in Ψ_s
(D) Decrease in Ψ_s → K^+ influx → Water influx → Hyperpolarization → H^+ efflux

2008

166. Comparing the mechanics of stomatal opening and closing, which process relies heavily on the opening of anion channels (like SLAC1) to depolarize the membrane?
(A) Opening
(B) Both opening and closing
(C) Neither; anion channels are inactive in guard cells
(D) Closing

2016

167. All of the following cellular events promote stomatal opening EXCEPT:
(A) Activation of plasma membrane H^+ -ATPases.
(B) Accumulation of malate in the vacuole.
(C) Synthesis of sugars from starch degradation.
(D) Efflux of potassium and chloride ions.

2008

168. Guard cells exhibit a specific and highly sensitive stomatal opening response to which specific quality of light?
(A) Blue light
(B) Far-red light
(C) Green light
(D) Ultraviolet-C light

2018

169. Vapor Pressure Deficit (VPD) represents the difference between the amount of moisture in the air and:
(A) Moisture the air can hold at saturation.
(B) The absolute humidity of the soil water.
(C) Internal CO_2 concentration of the leaf.

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(D) Wind speed at the boundary layer surface.

2006

170. Identify the correct statement regarding Abscisic Acid (ABA) signaling in guard cells.
(A) Promotes the permanent opening of stomata.
(B) Inhibits starch conversion without ion effect.
(C) Produced only in roots and takes days to act.
(D) Binding triggers calcium and opens channels.

2021

171. A sudden increase in the internal CO_2 concentration (C_i) within the substomatal cavity typically triggers:
(A) Stomatal closure
(B) Stomatal opening to acquire more carbon
(C) No response, guard cells are blind to CO_2
(D) Immediate shedding of the leaf

2023

172. Phototropins (phot1 and phot2) act as the primary photoreceptors in guard cells for initiating opening. What specific wavelength range do they absorb?
(A) Red (660 nm)
(B) Far-red (730 nm)
(C) Blue (400-500 nm)
(D) Infrared (>800 nm)

2024

173. During ABA-induced stomatal closure, which ion serves as a critical ubiquitous intracellular second messenger?
(A) Na^{+}
(B) $Mg^{\{2+\}}$
(C) $Ca^{\{2+\}}$
(D) $Fe^{\{3+\}}$

2013

174. Identify the INCORRECT statement regarding environmental cues and stomatal regulation.
(A) High temperatures promote opening to a point.
(B) High relative humidity (low VPD) keeps stomata open.
(C) Stomata close in response to a drop in potential.
(D) High CO_2 forces stomata to open widely.

2024

175. Determine the correct order of the ABA signaling cascade leading to stomatal closure.
I. Activation of outward-rectifying K^{+} channels
II. ABA binds to PYR/PYL/RCAR receptors
III. Decrease in guard cell turgor
IV. Elevation of cytosolic $Ca^{\{2+\}}$ and ROS production
(A) II, IV, I, III
(B) IV, II, I, III
(C) II, I, IV, III
(D) I, II, III, IV

2006

176. Comparing the efficiency of red and blue light in promoting stomatal opening, experimental evidence shows that:
(A) Blue light is more effective than red light.
(B) Red light is efficient while blue has no effect.
(C) Both wavelengths are exactly equal in efficiency.
(D) Red light operates via phototropin receptors.

2008

177. Which of the following conditions generally does NOT cause stomatal closure?
(A) Severe soil water deficit
(B) High levels of endogenous ABA
(C) Exposure to high intensity blue light
(D) Abnormally high atmospheric CO_2 levels

2017

178. Leaf Area Index (LAI) is defined in plant physiology and agronomy as:
(A) The one-sided leaf area per unit ground area.
(B) The ratio of total leaf mass to total stem mass.
(C) The angle of the leaf relative to incident rays.
(D) The percentage of leaf area covered by stomata.

2010

179. Identify the correct statement regarding the effect of relative humidity on transpiration.
(A) Rate is inversely proportional to humidity.
(B) High humidity increases the vapor gradient.
(C) Humidity has no effect if stomata are open.
(D) Rate reaches its maximum at 100% humidity.

2014

180. A moderate increase in wind speed typically increases the transpiration rate initially by:
(A) Sweeping away the boundary layer of air.
(B) Forcing stomata to open wider mechanically.
(C) Heating the leaf surface due to air friction.
(D) Increasing the internal CO_2 concentration.

2023

181. A plant native to a windy, arid environment possesses a very thick boundary layer due to

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dense trichomes and a recessed leaf shape. This adaptation functions to:
(A) Increase resistance to water vapor diffusion.
(B) Maximize the sensible heat loss from leaves.
(C) Accelerate the rate of cuticular transpiration.
(D) Reflect all photosynthetically active radiation.

2008

182. As ambient temperature rises, the water holding capacity of the air increases exponentially. This causes the vapor pressure deficit (VPD) to:
(A) Increase, providing a driving force for flow.
(B) Decrease, thus slowing cellular transpiration.
(C) Remain constant regardless of temperature.
(D) Collapse to zero at very high temperatures.

2019

183. Identify the INCORRECT statement regarding plant structural adaptations to limit transpiration.
(A) A thick, waxy cuticle increases resistance.
(B) Leaf curling reduces the exposed surface area.
(C) Sunken stomata increase the diffusion distance.
(D) High stomatal frequency reduces water loss.

2007

184. Trichomes (leaf hairs) reduce transpiration primarily by:
(A) Secreting antitranspirant chemicals to cells.
(B) Actively absorbing water from the atmosphere.
(C) Blocking the stomatal pores physically in situ.
(D) Trapping still air to increase resistance.

2011

185. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): Xerophytes often possess sunken stomata located in deep crypts on the leaf surface.
Reason (R): Sunken stomata lengthen the diffusion pathway for water vapor and shelter the pore from air currents, thereby reducing transpiration.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2011

186. Comparing the transpirational driving force in environments of 20% vs. 80% relative humidity (at constant temperature), the driving force is:
(A) Much greater at 20% RH
(B) Much greater at 80% RH
(C) Identical in both
(D) Unpredictable without knowing soil moisture

2013

187. All of the following micrometeorological variables generally act to increase transpiration rates EXCEPT:
(A) High incident solar radiation
(B) High ambient temperature
(C) High atmospheric relative humidity
(D) Moderate wind speeds breaking the boundary layer

2019

188. An antitranspirant is broadly defined as any material applied to transpiring plant surfaces for the purpose of:
(A) Reducing water loss from the plant
(B) Enhancing photosynthetic CO_2 uptake
(C) Increasing the reflection of ultraviolet light only
(D) Eradicating fungal pathogens

2009

189. Phenylmercuric acetate (PMA) functions as an antitranspirant primarily through which mechanism?
(A) Forming a physical plastic film over the leaf
(B) Reflecting incident solar radiation
(C) Inducing partial stomatal closure
(D) Destroying the waxy cuticle

2015

190. Identify the correct statement regarding film-forming antitranspirants.
(A) Use of plastics or waxes to block stomata.
(B) Selectively allowing water vapor to escape.
(C) Increasing photosynthesis simultaneously.
(D) Operating by mimicking natural ABA signals.

2014

191. Kaolin is often sprayed on crops as a reflectant antitranspirant. Its primary mode of action in reducing transpiration is to:
(A) Increase leaf albedo, reducing temperature.
(B) Physically plug the stomatal pore in situ.
(C) Poison the guard cell K^+ pumps chemically.
(D) Increase boundary layer resistance chemically.

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2009

192. Applying exogenous Abscisic Acid (ABA) acts as an effective antitranspirant because it directly causes:
(A) Defoliation of active leaves in plants.
(B) Inactivation of Rubisco enzyme activity.
(C) Deposition of additional cutin on leaves.
(D) Rapid stomatal closure via ion flux shifts.

2004

193. Which type of antitranspirant has the major drawback of often severely limiting CO_2 diffusion for photosynthesis as much as, or more than, it limits water vapor diffusion?
(A) Reflectants
(B) Metabolic stomatal closers at low concentrations
(C) Colorless leaf dyes
(D) Film-forming compounds

2011

194. Identify the INCORRECT statement regarding the usage and efficacy of antitranspirants in agriculture.
(A) They are economically viable for high-value crops like fruit trees and nursery transplants.
(B) They provide a permanent, lifelong solution to drought stress with a single application.
(C) Stomatal-closing types often require precise concentration control to avoid phytotoxicity.
(D) Reflectants can inadvertently reduce photosynthesis by lowering the amount of PAR reaching the chloroplasts.

2001

195. Match the antitranspirant chemicals/materials in List-I with their functional category in List-II.
List I: (Materials)
P. Kaolin
Q. Abscisic Acid
R. Silicone emulsion
S. Phenylmercuric acetate
List II: (Categories)
1. Film-forming compound
2. Reflectant
3. Endogenous stomatal closer
4. Exogenous chemical stomatal closer
(A) P-2, Q-3, R-1, S-4
(B) P-1, Q-4, R-2, S-3
(C) P-3, Q-2, R-4, S-1
(D) P-2, Q-4, R-1, S-3

2015

196. Comparing reflectant and film-forming antitranspirants, which is less likely to severely block CO_2 entry into the leaf?
(A) Film-forming antitranspirants
(B) Reflectant antitranspirants
(C) Both block CO_2 entry equally and totally
(D) Neither blocks CO_2, they only block water

2013

197. Which of the following compounds is NOT classified as a reflectant type antitranspirant?
(A) Kaolin clay
(B) Calcium carbonate suspensions
(C) Diatomaceous earth washes
(D) Waxy emulsions

2013

198. Water Use Efficiency (WUE) at the whole-plant level is typically defined as the ratio of:
(A) Biomass produced to water transpired.
(B) Water transpired to water absorbed.
(C) Yield produced to total rainfall.
(D) Stomatal to cuticular conductance.

2024

199. The Transpiration Ratio (TR) is mathematically related to WUE in what way?
(A) TR is directly proportional to WUE.
(B) TR is identical to intrinsic WUE.
(C) TR has no relation to WUE metrics.
(D) TR is the inverse of Water Use Efficiency.

2013

200. Identify the correct distinction between instantaneous WUE and intrinsic WUE.
(A) Instantaneous is $\frac{A}{E}$; intrinsic is $\frac{A}{g_s}$.
(B) Instantaneous uses isotopes; intrinsic uses gas.
(C) Instantaneous is seasonal; intrinsic is second.
(D) Both are exactly the same metric in units.

2012

201. Crassulacean Acid Metabolism (CAM) plants achieve the highest Water Use Efficiency among all photosynthetic types primarily because they:
(A) Elimination of the need for leaf stomata.
(B) Opening stomata at night when VPD is low.
(C) Lacking Rubisco enzyme within the leaves.
(D) Fixation through cuticular pathways only.

2018

202. C4 plants generally exhibit double the WUE of typical C3 plants. This is physiologically due to their ability to:
(A) High photosynthesis at low CO_2 concentrations.
(B) Operation with a higher stomatal conductance.
(C) Halting transpiration during the day entirely.

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(D) Absorbing water directly from the ambient air.

2012

203. Identify the INCORRECT pair regarding typical Transpiration Ratios (moles H_2O transpired per mole CO_2 fixed).
(A) CAM plants - 50 to 100
(B) C4 plants - 250 to 300
(C) C3 plants - 400 to 500
(D) C4 plants - 800 to 1000

2022

204. The exceptionally high intrinsic WUE of CAM plants is a direct evolutionary cause-and-effect consequence of:
(A) Temporal separation of CO_2 uptake and fixation.
(B) Spatial separation of bundle sheath and mesophyll.
(C) Loss of the waxy cuticle on the leaf surface.
(D) Symbiotic nitrogen fixation in the root nodules.

2025

205. Comparing C3 and C4 plants under high temperature and high light conditions, which group maintains a superior WUE and why?
(A) C3, because photorespiration generates extra water.
(B) C4, because PEP carboxylase suppresses photorespiration.
(C) C3, because they have thicker leaves in the canopy.
(D) C4, because they convert all CO_2 into starch instantly.

2001

206. All of the following variables directly factor into the calculation of instantaneous Water Use Efficiency ($\frac{A}{E}$) EXCEPT:
(A) Net assimilation rate of CO_2
(B) Transpiration rate
(C) Root nodule count
(D) Boundary layer resistance

2005

207. Which option provides the most accurate physiological definition of "intrinsic Water Use Efficiency" (WUE_i)?
(A) The ratio of net CO_2 assimilation to conductance.
(B) Total seed yield per liter of irrigation water applied.
(C) The ratio of leaf area to transpired water volume.
(D) The difference between stomatal and cuticular flow.

2009

208. Which photosynthetic pathway inherently exhibits the lowest Water Use Efficiency under typical warm, dry agricultural conditions?
(A) CAM
(B) C4
(C) C3
(D) Both C4 and CAM are equally low

2022

209. Carbon isotope discrimination ($\Delta^{13}C$) is a highly effective proxy for measuring long-term WUE in C3 plants. It is based on the preferential fixation of:
(A) ${}^{14}C$ over ${}^{12}C$ by PEP carboxylase.
(B) ${}^{12}C$ over ${}^{13}C$ by the enzyme Rubisco.
(C) ${}^{13}C$ over ${}^{12}C$ during cell respiration.
(D) ${}^{14}C$ over ${}^{13}C$ by the leaf guard cells.

2002

210. Identify the correct statement regarding carbon isotope discrimination ($\Delta^{13}C$) and WUE in C3 crops.
(A) Low values indicate closed stomata and high WUE.
(B) A higher value correlates strongly with high WUE.
(C) Isotope discrimination is independent of conductance.
(D) C4 plants show massive fluctuations compared to C3.

2006

211. When utilizing infrared gas exchange analyzers (IRGA) to evaluate breeding lines for WUE, researchers are directly measuring:
(A) Instantaneous CO_2 assimilation and transpiration.
(B) Whole plant biomass accumulation over the season.
(C) Final grain yield per hectare in the field site.
(D) Soil moisture depletion rates across the profile.

2012

212. Whole-plant lysimetry is an agronomic methodology used to measure WUE by accurately tracking:
(A) Weight changes of soil-plant systems for loss.
(B) Minute changes in isotopic carbon ratios in gas.
(C) The electrical sap flow within the xylem tissue.

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(D) The fluorescence of chlorophyll under drought.

2004

213. Because Rubisco discriminates against the heavier ${}^{\{13\}}CO_2$ molecule, plants that keep their stomata partially closed (high WUE) will force Rubisco to:
(A) Fix only ${}^{\{12\}}CO_2$ exclusively in the stroma.
(B) Fix a higher proportion of heavier ${}^{\{13\}}CO_2$ molecules.
(C) Cease carbon fixation entirely in the chloroplast.
(D) Switch to the PEP carboxylase pathway for carbon.

2014

214. Agronomic strategies to improve crop WUE at the field level often include:
(A) Increasing planting density to maximize soil loss.
(B) Tillage practices that reduce the soil evaporation.
(C) Removing windbreaks to maximize the conductance.
(D) Flooding the field continuously with surface water.

2023

215. Identify the INCORRECT statement regarding the genetic improvement of WUE.
(A) Breeding for lower $\Delta^{13}C$ in wheat has successfully produced cultivars with improved WUE.
(B) Selecting for deeper root systems can improve drought avoidance, though not strictly intrinsic WUE.
(C) Altering leaf morphology to reduce the boundary layer can influence WUE.
(D) Permanent stomatal closure is a successful strategy for yield WUE.

2005

216. Comparing the carbon isotope discrimination ($\Delta^{13}C$) of C3 and C4 plants, it is generally observed that:
(A) C4 plants discriminate more heavily against ${}^{\{13\}}C$.
(B) C4 plants discriminate less against heavy carbon.
(C) Both pathways discriminate equally against ${}^{\{13\}}C$.
(D) C3 plants fix heavy carbon exclusively in cells.

2024

217. Which of the following is NOT a recognized methodology for assessing or measuring Water Use Efficiency?
(A) Gravimetric whole-plant lysimetry analysis.
(B) Carbon isotope ratio mass spectrometry methods.
(C) Leaf gas exchange (IRGA) profiling techniques.
(D) High-performance liquid chromatography of pigments.

2003

218. The most viable and long-lasting strategy for genetic enhancement of WUE in staple crops like wheat involves:
(A) Breeding for optimal LAI and favorable alleles.
(B) Coating seeds in antitranspirants before sowing.
(C) Spraying gibberellic acid weekly on the canopy.
(D) Mutating the plants to lack a waxy leaf cuticle.

2008

219. All of the following practices generally improve agricultural water use efficiency EXCEPT:
(A) Drip irrigation replacing flood irrigation.
(B) Mulching to minimize the soil evaporation.
(C) Cultivating varieties with a high Harvest Index.
(D) Excessive nitrogen leading to uncontrolled growth.

2011

220. The Membrane Stability Index (MSI) is a physiological marker used in drought resistance assessment. It primarily measures:
(A) Leakage of electrolytes from leaf tissue discs.
(B) Structural thickness of the cell wall in situ.
(C) Ratio of saturated to unsaturated fatty acids.
(D) The rate of aquaporin synthesis in membranes.

2012

221. Canopy Temperature Depression (CTD) is measured using infrared thermometry. A cooler canopy relative to the ambient air temperature typically indicates:
(A) Severe drought stress and stomatal closure.
(B) Active transpiration and access to soil moisture.
(C) A complete lack of cuticular waxes on the leaf.

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(D) Xylem cavitation occurring in all vessels.

2011

222. Identify the correct statement regarding osmotic adjustment as a drought tolerance mechanism.
(A) Passive loss of water to concentrate solutes.
(B) Active accumulation of compatible osmolyte solutes.
(C) An immediate increase in total water potential.
(D) Presence only in halophytes, not in mesophytes.

2014

223. Proline accumulation during water deficit acts as a compatible osmolyte. Its primary physiological role is to:
(A) Act as a toxic repellant to herbivores in stress.
(B) Lower osmotic potential without interfering with enzymes.
(C) Block the plasmodesmata to prevent water loss.
(D) Physically stiffen the primary cell wall of the leaf.

2007

224. Glycine betaine is heavily synthesized by many drought-resistant plants under stress. Beyond osmotic adjustment, it heavily contributes to:
(A) Stabilization of Photosystem II and membrane integrity.
(B) Rapid degradation of mRNA molecules in the cytoplasm.
(C) Increased cuticular transpiration from the epidermis.
(D) Inhibition of primary root elongation during stress.

2008

225. Leaf rolling is a common morphological response to drought stress in grasses. The cause-and-effect physiological mechanism driving this involves:
(A) Loss of turgor in specialized epidermal bulliform cells.
(B) Active contraction of leaf mesophyll active filaments.
(C) Lignification of the midrib during tissue development.
(D) Rapid synthesis of abscisic acid in the leaf margins.

2008

226. Identify the INCORRECT statement regarding physiological markers of drought resistance.
(A) A higher MSI indicates greater cellular tolerance to dehydration.
(B) Increased levels of reactive oxygen species (ROS) scavenging enzymes correlate with better drought tolerance.
(C) High relative water content (RWC) retention under soil deficit is a positive marker for drought tolerance.
(D) Cultivars with higher CTD (cooler canopies) under stress are often more drought-susceptible.

2012

227. Comparing a drought-tolerant and a drought-susceptible wheat cultivar subjected to the same water deficit, the tolerant cultivar typically exhibits:
(A) A cooler canopy temperature and higher water content.
(B) A much warmer canopy temperature relative to air.
(C) Rapid and complete leaf senescence within a day.
(D) A significantly lower Membrane Stability Index.

2013

228. Which of the biochemicals is NOT typically classified as a compatible solute or osmoprotectant during drought stress?
(A) Proline
(B) Trehalose
(C) Glycine betaine
(D) Lignin

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2024

229. All of the following metrics are reliable indicators of plant drought resistance or avoidance EXCEPT:
(A) High root-to-shoot biomass ratio in plants.
(B) Delayed leaf rolling score under severe VPD.
(C) Substantial osmotic adjustment via proline.
(D) Accelerated rate of xylem cavitation at tensions.

2001

230. Visual leaf wilting and rolling scores are frequently used in large-scale breeding programs because they:
(A) Provide a rapid, integrated assessment of stress.
(B) Precisely quantify the leaf water potential in MPa.
(C) Replace the need for measuring final grain yield.
(D) Are unaffected by external temperature or wind.

ANSWERS

1. (A) Cellulose
Cellulose consists of beta-1,4-linked glucose chains forming microfibrils. It provides high tensile strength and structural integrity to the primary wall. These microfibrils are embedded in a matrix of hemicellulose and pectin. Cellulose is synthesized by large complexes in the plasma membrane. Its crystalline nature makes it the primary structural polymer in most terrestrial plant species.

2. (C) Symplastic communication
Plasmodesmata are narrow channels that traverse cell walls, connecting the cytoplasm of adjacent cells. This creates a continuous symplastic network throughout the plant body. They facilitate the transport of water, ions, and small molecules directly between cells. Larger molecules like proteins and RNAs also move through these channels via regulated mechanisms. This system is crucial for long-distance signaling and resource distribution.

3. (A) It cross-links cellulose microfibrils as a tethering glycan.
Hemicelluloses are branched polysaccharides that associate with cellulose microfibrils through hydrogen bonding. They act as tethering molecules that cross-link microfibrils into a strong, flexible network. Common types include xyloglucans in dicots and glucuronoarabinoxylans in monocots. This architecture allows for wall expansion while maintaining structural coherence. They are primarily synthesized within the Golgi apparatus before secretion into the wall space.

4. (D) It is heavily lignified in newly formed primary tissues.
The middle lamella is the outermost layer between adjacent plant cells, functioning primarily as an adhesive. It consists mostly of pectic polysaccharides, particularly homogalacturonan. These pectins form gels when cross-linked by calcium and magnesium ions. While lignification occurs later in woody tissues, primary tissues lack significant lignin. This layer is the first formed during cytokinesis, originating from the cell plate.

5. (A) Both A and R are true and R is the correct explanation of A.
Secondary walls are deposited internally to the primary wall after cell expansion has ceased. This layer is characterized by high cellulose content and the presence of lignin, which adds rigidity. Since lignin and specialized protein arrangements prevent further stretching, cells cannot grow once this wall is complete. Therefore, the lack of expansins and the presence of rigid polymers define this developmental stage.

6. (C) Lignin
Lignin is a complex phenolic polymer that infiltrates the spaces between cellulose, hemicellulose, and pectin. It provides extreme compressive strength and waterproofing to vascular tissues and woody parts. By replacing water in the wall, it restricts porosity and prevents biological degradation. This chemical modification is essential for structural support in tall plants and efficient water conduction through the xylem vessels.

7. (D) Pectic polysaccharides
Homogalacturonan and rhamnogalacturonan are major components of the pectin matrix in plant cell walls. They are rich in galacturonic acid, which provides negative charges. These polysaccharides are essential for controlling wall porosity and cell-to-cell adhesion. Pectins form a hydrated gel-like environment that surrounds the cellulose-hemicellulose network. They are highly abundant in the middle lamella and the primary cell wall layers.

8. (A) Deposition in three distinct anisotropic layers (S1, S2, S3)
Secondary cell walls are structured into three distinct layers called S1, S2, and S3. These layers differ in the orientation of their cellulose microfibrils, providing enhanced mechanical strength. Unlike the primary wall, which is deposited during growth, the secondary wall forms after growth stops. It is typically much thicker and often contains lignin. This multi-layered architecture is a hallmark of wood and fibers.

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9. (B) Pit membranes with extensive torus development
Primary cell walls are thin and flexible, containing cellulose, xyloglucans, and pectins. Extensin proteins are also characteristic structural components that reinforce these walls. However, highly developed pit membranes with a central torus are specialized features found in the secondary walls of tracheary elements, especially in gymnosperms. Primary walls typically feature simple pits or primary pit fields where plasmodesmata cluster together without such complex thickening.

10. (A) P-4, Q-3, R-2, S-1
Cellulose forms the primary scaffold providing tensile strength. Pectins are highly hydrated polysaccharides that form gel-like matrices. Lignin confers mechanical rigidity and hydrophobicity, especially in vascular tissues. Callose is a specialized beta-1,3-glucan synthesized in response to wounding or stress to seal plasmodesmata and sieve plates. Each component plays a distinct role in maintaining the physical and physiological integrity of the plant cell wall.

11. (A) Singer and Nicolson
The fluid mosaic model, proposed in 1972, describes the plasma membrane as a dynamic lipid bilayer. This bilayer acts as a solvent for integral and peripheral proteins. The proteins are distributed like a mosaic and can move laterally within the membrane. This conceptual framework replaced earlier, more rigid models. It explains how membranes maintain stability while allowing for transport, signaling, and various biochemical interactions.

12. (C) Increased proportion of unsaturated fatty acids in the bilayer
Lowering environmental temperatures causes membranes to become less fluid and more gel-like. To compensate, plants increase the proportion of unsaturated fatty acids in their phospholipids. The kinks in unsaturated hydrocarbon tails prevent tight packing, thereby lowering the transition temperature. This adjustment maintains the liquid-crystalline state necessary for protein function. This process is a critical part of cold acclimation and chilling tolerance.

13. (D) Allowing rapid, regulated, and bidirectional bulk flow of water
Aquaporins are specialized channel proteins that facilitate the rapid movement of water across biological membranes. While water can diffuse through the lipid bilayer slowly, aquaporins allow for much higher flux rates. These channels are highly specific and can be regulated by gating mechanisms like pH or phosphorylation. They do not use energy and allow water to flow bidirectionally based on the water potential.

14. (C) Carrier proteins
Carrier proteins, also known as transporters, bind specific solutes and undergo a series of conformational changes to move them across the membrane. This process is typically slower than transport via channel proteins. Carriers can facilitate either passive transport (facilitated diffusion) or active transport against a gradient. The specificity of the binding site ensures that only particular molecules or ions are transported across the lipid bilayer.

15. (B) II and III
Channel proteins facilitate passive transport by creating selective pores, not active transport. Carrier proteins are versatile and can mediate both passive and active transport through conformational shifts. Aquaporins are a specific class of channel proteins dedicated to water molecules. Therefore, the statements identifying carrier versatility and aquaporin classification are accurate. These proteins are essential for maintaining cellular homeostasis and responding to various environmental osmotic fluctuations.

16. (D) It requires moving a hydrophilic head through a hydrophobic core
Transverse diffusion, or flip-flop movement, involves a phospholipid migrating from one leaflet of the bilayer to the other. This process is energetically unfavorable because the polar hydrophilic head must pass through the nonpolar hydrophobic fatty acid core. While lateral diffusion occurs rapidly, flip-flopping happens very slowly unless facilitated by specific enzymes like flippases. This restriction helps maintain the asymmetrical distribution of lipids across membranes.

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17. (A) Narrow selectivity filters exclude protons to maintain gradients
Aquaporins possess a highly specialized selectivity filter, often involving conserved asparagine-proline-alanine (NPA) motifs. This filter allows water molecules to pass in a single file while strictly excluding protons and other ions. Preventing proton leakage is essential for maintaining the electrochemical gradients required for ATP synthesis and active transport. While some aquaporins allow small uncharged solutes, their primary role is regulated and selective water conduction.

18. (C) It is entirely impermeable to gases like CO_2 and oxygen.
The plasma membrane is a semi-permeable barrier that regulates the entry and exit of substances. It contains sterols to modulate fluidity and houses proteins like cellulose synthase. It maintains an electrical potential across the bilayer through ion pumping. However, it is not entirely impermeable to small nonpolar gases. Carbon dioxide and oxygen can diffuse directly through the lipid bilayer and via certain channel proteins.

19. (A) Reactive oxygen species modifying cysteine residues
Under drought stress, plants produce reactive oxygen species (ROS) as part of a signaling cascade. These ROS can directly modify specific cysteine residues on aquaporin proteins, leading to the closure or gating of the channel. This mechanism helps the plant conserve water by reducing membrane permeability. Other factors like pH and phosphorylation also regulate gating, but ROS-mediated modification is a key response to environmental stress.

20. (A) Solute binding, ATP hydrolysis, conformational change, solute release
Primary active transport involves a specific sequence of molecular events. First, the solute binds to a high-affinity site on the carrier protein. ATP is then hydrolyzed, often resulting in the phosphorylation of the protein. This energy release triggers a major conformational change that reduces solute affinity and exposes the binding site to the opposite side. Finally, the solute is released into the compartment.

21. (B) Smooth Endoplasmic Reticulum
The smooth endoplasmic reticulum is the primary organelle responsible for the synthesis of various lipids, including phospholipids and sterols. Unlike the rough ER, it lacks attached ribosomes. In addition to lipid biosynthesis, it plays a role in carbohydrate metabolism and detoxification processes. The synthesized lipids are subsequently transported to other organelles or the plasma membrane via vesicles or through direct contact sites between membranes.

22. (C) Vacuole
The tonoplast is the specialized semi-permeable membrane that separates the central vacuole from the cytoplasm. It contains various transport proteins, including proton pumps and aquaporins, which regulate the movement of water and solutes. By maintaining a high concentration of ions and metabolites inside the vacuole, the tonoplast plays a vital role in generating turgor pressure. This membrane is essential for cellular expansion and storage.

23. (D) Water influx driving expansion and turgor maintenance
The accumulation of osmotically active solutes, such as sugars and ions, lowers the osmotic potential within the vacuole. This creates a gradient that draws water from the cytoplasm and the exterior into the vacuole through osmosis. The resulting hydrostatic pressure, known as turgor pressure, pushes against the cell wall. Turgor is essential for maintaining the structural rigidity of non-woody plants and driving cell expansion.

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24. (A) Golgi bodies
Golgi bodies, or dictyosomes, are the central sites for the synthesis of complex non-cellulosic polysaccharides like pectins and hemicelluloses. These materials are packaged into secretory vesicles that transport them to the plasma membrane for incorporation into the cell wall. Consequently, cells actively involved in cell wall deposition show an extensive proliferation of Golgi stacks. This organelle is critical for both modifying proteins and synthesizing wall matrix components.

25. (B) II and IV
The endomembrane system includes the nuclear envelope, ER, Golgi, and vacuoles, which are functionally linked. The nuclear envelope is continuous with the rough ER, and Golgi bodies consist of stacked cisternae. However, vacuoles possess many transport proteins in their

tonoplast, such as V-type ATPases. Additionally, mitochondria and chloroplasts are not part of the endomembrane system as they are semi-autonomous and have double membranes.

26. (B) Tonoplast - Storage of calcium ions and secondary metabolites
The tonoplast is the vacuolar membrane that houses transporters for sequestering various substances. Vacuoles serve as primary storage sites for calcium ions, organic acids, and secondary metabolites like anthocyanins or alkaloids. This sequestration helps maintain cytosolic homeostasis and provides defense against herbivores. While the ER synthesizes proteins and lipids and the Golgi modifies polysaccharides, the tonoplast's storage and regulatory functions are critical for mature plant cells.

27. (A) Nucleolus - Site of lipid synthesis
The nucleolus is a dense region within the nucleus primarily responsible for the synthesis of ribosomal RNA and the assembly of ribosomal subunits. It is not involved in lipid synthesis, which occurs in the smooth endoplasmic reticulum. The endoplasmic reticulum acts as a transport network, dictyosomes are the plant equivalents of the Golgi, and vacuoles handle the degradation of various cellular macromolecules.

28. (C) Presence of attached ribosomes for protein synthesis
The rough endoplasmic reticulum is distinguished by the presence of ribosomes attached to its cytosolic surface. These ribosomes are actively involved in the translation of proteins destined for secretion, membrane insertion, or sequestration within the endomembrane system. In contrast, the smooth ER lacks ribosomes and is primarily involved in lipid metabolism and calcium storage. The rough ER typically forms flattened sacs called cisternae.

29. (D) Chloroplast
The endomembrane system consists of the nuclear envelope, endoplasmic reticulum, Golgi apparatus, vacuoles, and the plasma membrane. These components are linked via direct physical continuity or vesicle transport. Chloroplasts and mitochondria are excluded because they are semi-autonomous, possess their own DNA, and do not participate in the standard vesicular trafficking of the endomembrane system. They originated through endosymbiosis and maintain a double-membrane structure.

30. (A) II, III, I, IV
The standard secretory pathway begins with protein or lipid synthesis in the rough endoplasmic reticulum. These products are then transported via vesicles to the Golgi apparatus for further modification, sorting, and packaging. Modified substances are subsequently loaded into secretory vesicles that migrate toward the cell periphery. Finally, these vesicles fuse with the plasma membrane, releasing their contents into the extracellular space or the cell wall.

31. (B) Activity of V-type H^+-ATPase and H^+-PPase
The internal environment of the vacuole is significantly more acidic than the surrounding cytoplasm. This pH gradient is maintained by the active transport of protons across the tonoplast. Two primary enzymes drive this process: the vacuolar-type H^+-ATPase (V-ATPase) and the H^+-pyrophosphatase (H^+-PPase). These pumps utilize the energy from ATP or inorganic pyrophosphate to accumulate protons, which then facilitates the secondary transport of other solutes.

32. (D) Thylakoids
Chloroplasts contain an intricate internal membrane system composed of flattened, sac-like structures called thylakoids. These membranes are the primary site for the light-dependent reactions of photosynthesis. Thylakoids are often stacked into structures known as grana, which are connected by stroma lamellae. The thylakoid membrane houses chlorophyll pigments, electron transport chains, and ATP synthase complexes. The space inside these sacs is called the thylakoid lumen.

33. (A) Inner membranes contain the electron transport chain.
Mitochondria are the sites of cellular respiration, where the inner membrane is highly folded into cristae to increase surface area. This inner membrane houses the protein complexes of the electron transport chain and the ATP synthase. Unlike chloroplasts, they do not perform the Calvin cycle. Mitochondria contain their own circular DNA and ribosomes, allowing them to produce some of their own proteins.

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34. (C) Peroxisome
Under conditions of high light and low carbon dioxide, the enzyme Rubisco binds oxygen instead of CO_2, initiating photorespiration. This process produces phosphoglycolate, which is toxic to the cell. Peroxisomes contain essential enzymes that convert glycolate into glycine, a key step in the photorespiratory cycle. This organelle works in close coordination with chloroplasts and mitochondria to recover carbon and detoxify the intermediates produced during oxygenation.

35. (A) I, II, III and IV
Mitochondria and chloroplasts generate ATP through oxidative and photophosphorylation, respectively. Glyoxysomes are specialized for converting lipids to carbohydrates in germinating seeds. Peroxisomes play a vital role in the photorespiratory pathway. Amyloplasts, however, are primarily responsible for the synthesis and storage of starch grains rather than lipids. Therefore, the statements regarding energy production, the glyoxylate cycle, and photorespiration are correct, while the amyloplast claim is not.

36. (D) They are highly active in mature, photosynthesizing leaves.
Glyoxysomes are specialized microbodies predominantly found in the storage tissues of oil-rich seeds during germination. They contain the enzymes necessary for beta-oxidation and the glyoxylate cycle, which convert stored fats into sugars for seedling growth. Once the plant begins photosynthesis and the lipid reserves are exhausted, glyoxysomes typically disappear or transform into leaf peroxisomes. They are not active in mature, photosynthesizing leaves where energy is derived from light.

37. (B) Chloroplast, Peroxisome, Mitochondrion
Photorespiration is a complex metabolic pathway that requires the coordinated effort of three different organelles. It begins in the chloroplast when Rubisco acts as an oxygenase. The intermediates then move to the peroxisome for further processing and then to the mitochondrion, where carbon dioxide is released. The cycle then returns through the peroxisome back to the chloroplast. This pathway is essential for recycling carbon lost during the oxygenation of RuBP.

38. (C) Accumulation of protons across a membrane
ATP synthesis in both mitochondria and chloroplasts is explained by the chemiosmotic hypothesis. During electron transport, energy is used to pump protons across a membrane, creating an electrochemical proton gradient. In mitochondria, protons accumulate in the intermembrane space, while in chloroplasts, they accumulate in the thylakoid lumen. The subsequent flow of protons back through the ATP synthase complex provides the rotational energy required to synthesize ATP from ADP.

39. (D) Grana stacks
While both mitochondria and chloroplasts possess a double boundary membrane, circular DNA, and ATP synthase, grana stacks are exclusive to chloroplasts. Grana are composed of stacked thylakoid membranes where the light-harvesting complexes and electron transport machinery are concentrated. These structures are essential for the efficient capture of light energy during photosynthesis. Mitochondria utilize cristae, which are inward folds of the inner membrane, rather than separate stacked sacs.

40. (A) Chromoplasts
Chromoplasts are specialized, pigment-containing plastids responsible for the yellow, orange, and red colors observed in many flowers, fruits, and some roots. They develop from chloroplasts or proplastids and synthesize large quantities of carotenoids. These pigments serve to attract pollinators and seed dispersers. Unlike amyloplasts or elaioplasts, which store starch and lipids respectively, chromoplasts focus on the synthesis and storage of lipid-soluble pigments within their internal membrane structures.

41. (B) Lipid to carbohydrate conversion to fuel early growth
Germinating oilseeds contain high concentrations of lipids, which are energy-dense but cannot be directly transported to the growing embryo. The glyoxylate cycle, occurring in glyoxysomes, allows these seeds to bypass certain steps of the citric acid cycle. This enables the net conversion of acetyl-CoA, derived from fatty acids, into succinate. Succinate is then converted into sugars through gluconeogenesis, providing the necessary carbohydrates for early seedling development before photosynthesis begins.

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42. (B) Peroxisomes
Mitochondria and chloroplasts are semi-autonomous organelles that contain their own circular DNA and ribosomal machinery, inherited maternally. Proplastids, being the undifferentiated precursors of all plastids, also carry the plastid genome. Peroxisomes, however, are single-membrane microbodies that lack their own genetic material. They depend entirely on the nuclear genome for the synthesis of their enzymes. Proteins are imported into peroxisomes from the cytoplasm using specific signaling sequences.

43. (A) Non-protoplasmic reserve or excretory products
Ergastic substances are non-living materials found within the plant cell that are not part of the active protoplasm. They include a wide variety of reserve materials like starch, proteins, and lipids, as well as waste products like crystals and tannins. These substances can be stored in the vacuole, the cell wall, or specialized plastids. They represent the metabolic byproducts or storage reserves essential for the plant's survival and environmental interactions.

44. (C) They are needle-like crystals of calcium oxalate.
Raphides are a common form of ergastic substance consisting of needle-shaped crystals of calcium oxalate. They typically occur in bundles within specialized cells called idioblasts. These crystals are often stored in the vacuole and serve as a defense mechanism against herbivory by causing physical irritation. They are distinct from cystoliths, which are made of calcium carbonate. Raphides are widely distributed among various families of monocots and some dicots.

45. (A) Both A and R are true and R is the correct explanation of A.
Cystoliths are specialized internal mineral deposits commonly found in the epidermis of plants like the rubber tree. They consist of calcium carbonate deposited on a stalk-like extension of the cell wall, known as a peg or body. This stalk is primarily made of cellulose. The formation of cystoliths is a characteristic anatomical feature used in plant identification. Because the structure and composition are accurately described, both the assertion and reason are true.

46. (C) Aleurone grains are specialized lipid storage droplets.
Reserve food materials in plants are diverse and stored in different forms. Starch is the primary storage carbohydrate in amyloplasts, while inulin is a soluble fructose polymer found in plants like dahlias. Higher plants generally do not store glycogen. However, aleurone grains are specialized structures for storing proteins, not lipids. They are particularly abundant in the outer layers of cereal endosperm. Lipid storage typically occurs in oil bodies or elaioplasts.

47. (B) Proteins
Aleurone grains are specialized storage vacuoles found in the seeds of many plants, most notably in the aleurone layer of cereal grains. They primarily store proteins in a solid, dehydrated form. These proteins are utilized by the germinating embryo as a source of nitrogen and amino acids. In addition to proteins, aleurone grains often contain phytin, which serves as a reserve for phosphorus and various mineral cations required for early growth.

48. (D) Secretory ergastic substances
Ergastic substances are classified based on their role in the plant's metabolism. Reserve substances like starch are stored for later use, while excretory products are waste materials. Secretory substances, including essential oils, nectar, resins, and latex, are produced by specialized cells and released into cavities or onto the surface. These substances often serve ecological roles, such as attracting pollinators, repelling herbivores, or sealing wounds, rather than being simple metabolic waste.

49. (A) Ribosomes
Ergastic substances include non-protoplasmic materials such as metabolic byproducts and storage reserves. Tannins, cystoliths, and alkaloids are all classic examples of these non-living inclusions. Ribosomes, however, are active components of the cell's protoplasm. They are complex molecular machines made of RNA and proteins that facilitate protein synthesis. Because they are vital for the cell's metabolic activity and growth, they are not classified as ergastic or passive inclusions.

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50. (C) Raphides are needle-like bundles, whereas sphaeraphides are star-shaped clusters.
Both raphides and sphaeraphides are composed of calcium oxalate, which is insoluble and stored in the vacuole. Their primary difference lies in their crystalline morphology. Raphides form long, needle-like crystals that are usually found in dense, parallel bundles. Sphaeraphides, also known as druses, are spherical or star-shaped aggregates of many individual crystals. Both structures function as deterrents to herbivory. They are formed as a way to regulate calcium levels and provide defense.

51. (A) Alternating periods of carbohydrate deposition
Starch grains often exhibit a layered appearance under the microscope, characterized by concentric or eccentric rings called striations. These layers are the result of the rhythmic deposition of starch molecules over time. Variations in water content and the rate of carbohydrate synthesis during different periods of the day or growth stages lead to differences in the density of the deposited material. This process creates the visible structural bands surrounding the hilum of the grain.

52. (D) Glandular trichomes or specialized secretory cavities
Essential oils are often volatile and potentially toxic if accumulated in the cytoplasm of ordinary cells. To avoid damage, plants sequester these ergastic substances in specialized anatomical structures. These include glandular trichomes on the leaf surface or internal secretory cavities and ducts. These compartments prevent the oils from interfering with metabolic processes while ensuring they are available for ecological functions, such as defense against insects or protection from microbial pathogens.

53. (B) The mutual attractive force between water molecules
Cohesion is the physical property of water where individual water molecules are attracted to one another. This is primarily due to the formation of hydrogen bonds between the partially positive hydrogen atoms and the partially negative oxygen atoms of neighboring molecules. This mutual attraction creates a high internal pressure and tensile strength. Cohesion is fundamental to the formation of continuous water columns in the xylem, allowing water to be pulled to great heights.

54. (C) Polar attractions between hydrogen and oxygen atoms
Hydrogen bonding in water occurs because of the polar nature of the molecule. The oxygen atom is more electronegative than the hydrogen atoms, creating partial negative and positive charges. A hydrogen bond forms when the positive hydrogen of one water molecule is attracted to the negative oxygen of another. These are weak electrostatic attractions compared to covalent bonds, yet they are strong enough to provide water with its unique thermal and cohesive properties.

55. (A) P-2, Q-3, R-1, S-4
High specific heat allows water to absorb large amounts of energy with minimal temperature change, providing thermal stability. High latent heat of vaporization ensures significant cooling as water evaporates from leaves. Cohesion maintains the integrity of the water column under the high tension of the transpirational pull. Adhesion facilitates the attachment of water to the hydrophilic surfaces of xylem cell walls. Together, these properties enable efficient water transport and temperature regulation in plants.

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56. (A) Thermal buffering against rapid temperature changes
Specific heat capacity is the amount of energy required to raise the temperature of a substance. Water has an exceptionally high value, meaning it can gain or lose significant heat without changing its own temperature rapidly. This property provides a vital thermal buffer for plant tissues, protecting metabolic processes and enzyme functions from the fluctuations of the external environment. It helps maintain a relatively constant internal temperature during hot days or cold nights.

57. (B) Latent heat of vaporization
The latent heat of vaporization is the energy required to convert a liquid into a gas without changing its temperature. For water, this value is very high because many hydrogen bonds must be broken for molecules to escape into the vapor phase. When plants transpire, this energy is taken from the leaf tissue, leading to a substantial cooling effect. This process is the primary

mechanism for regulating leaf temperature under high solar radiation.

58. (B) Maintenance of water columns against gravity
Adhesion is the attraction between water molecules and solid, hydrophilic surfaces like the cellulose and lignin in xylem walls. This force prevents the water column from pulling away from the vessel walls under tension. Along with cohesion, adhesion is essential for the capillary rise of water and for maintaining the continuous thread of water needed for the ascent of sap. Without it, gravity would cause the water column to break and collapse.

59. (A) The H-O-H bond angle is exactly 180 degrees, making it linear.
The water molecule is not linear; instead, it has a bent geometry due to the two lone pairs of electrons on the oxygen atom. The actual H-O-H bond angle is approximately 104.5 degrees. This shape is responsible for its polarity, allowing it to act as an excellent solvent and form hydrogen bonds. Other properties like high surface tension and its polar nature are accurate descriptions of the water molecule's physical chemistry.

60. (C) Unbalanced cohesive forces at the air-water interface
Surface tension arises because water molecules at the air-water interface experience unequal attractive forces. While molecules in the bulk liquid are pulled in all directions by their neighbors, those at the surface are only pulled inward and laterally. This results in the surface behaving like a stretched elastic membrane. This property is crucial for maintaining water in soil pores and for the mechanics of water movement across cell membranes and through narrow xylem conduits.

61. (D) Its high dielectric constant facilitating ion separation
Water is the ideal solvent for biological systems because of its high dielectric constant. This property allows water to decrease the electrostatic attraction between oppositely charged ions, enabling them to dissolve and remain separated in solution. This facilitation of ion dissociation is critical for maintaining electrochemical gradients and for the activity of enzymes and metabolic pathways. Its low viscosity also allows for the rapid diffusion of solutes throughout the various cellular compartments.

62. (C) Low boiling point compared to other hydrides
Water exhibits several anomalous properties due to hydrogen bonding, including a high latent heat of fusion and expansion upon freezing. Its cohesiveness is vital for transport. However, water actually has an unusually high boiling point compared to other molecules of similar size, such as hydrogen sulfide. This high boiling point ensures that water remains in the liquid state over the range of temperatures typically found on Earth, which is essential for sustaining biological life.

63. (B) Imbibition
Imbibition is a specific type of diffusion where water is absorbed by solid particles, known as imbibants, causing them to swell. This process occurs due to the strong attraction between water and hydrophilic colloids like proteins and cellulose. It does not require a semi-permeable membrane and is driven by a very low matric potential. Imbibition is the critical first step in seed germination, as it provides the pressure needed to rupture the seed coat.

64. (D) Osmotic pressure
Osmotic pressure is defined as the maximum potential pressure that can develop in a solution if it is separated from pure water by a semi-permeable membrane. It is a colligative property that depends on the concentration of solute particles. While water potential describes the free energy of water, osmotic pressure is its positive numerical equivalent. In plant cells, it represents the force driving water influx, which is eventually balanced by the mechanical wall pressure.

65. (B) I and III
Incipient plasmolysis marks the stage where the protoplast just begins to pull away from the cell wall, and turgor pressure reaches zero. Severe plasmolysis occurs when the cell is placed in a hypertonic solution, causing extensive water loss and the complete detachment of the plasma membrane. Plasmolysis involves shrinking, not swelling; swelling occurs in hypotonic solutions. Understanding these stages is important for studying cell water relations and membrane permeability under various osmotic stresses.

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66. (C) Hydrostatic pressure of vacuolar fluid against the wall
Turgor pressure is the hydrostatic pressure exerted by the contents of the cell against the plasma membrane and cell wall. As water enters the vacuole via osmosis, the expanding protoplast pushes outward. This pressure is essential for maintaining the structural integrity of herbaceous plants and for driving processes like cell enlargement and stomatal movement. In a typical healthy plant cell, turgor pressure is positive, while in a plasmolyzed cell, it falls to zero.

67. (A) Concentration gradient of the solute
Fick's first law of diffusion states that the rate of movement of a substance is directly proportional to the concentration gradient. This means that a steeper difference in concentration between two regions will result in a faster net flux of molecules. Diffusion is a passive process driven by the random kinetic energy of molecules. Other factors, such as the diffusion coefficient and the surface area, also influence the rate, while distance traveled inversely affects it.

68. (D) Use of semi-permeable membranes for solvent flow
Both osmosis and simple diffusion are passive processes where substances move from regions of high potential to low potential without the use of ATP. However, osmosis is specifically defined as the diffusion of water or another solvent across a semi-permeable membrane. This membrane allows the solvent to pass while restricting the movement of most solutes. Simple diffusion does not require such a barrier and can occur in gases, liquids, or across fully permeable boundaries.

69. (B) Incipient plasmolysis
Incipient plasmolysis is the physiological point where the internal turgor pressure of a cell has dropped to exactly zero. At this stage, the plasma membrane begins to lose contact with the cell wall, typically starting at the corners. In a tissue sample, this point is defined when approximately 50% of the cells show these initial signs of shrinkage. This state is reached when the external solution is isotonic to the cell sap, meaning their potentials are equal.

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70. (C) Isotonic solution - Induces rapid cellular bursting
In a hypotonic solution, water enters the cell, creating turgor. In a hypertonic solution, water leaves, causing plasmolysis. A semi-permeable membrane selectively restricts solute movement. However, an isotonic solution has the same water potential as the cell sap, resulting in no net movement of water. In this state, cells become flaccid but do not burst. Rapid cellular bursting typically occurs in animal cells placed in highly hypotonic solutions due to the lack of a wall.

71. (D) Concentration of atmospheric CO_2
Imbibition is a physical process driven by the water potential gradient and the affinity between the imbibant and water. Temperature affects the kinetic energy of water molecules and the rate of absorption. However, atmospheric carbon dioxide concentration has no direct influence on the physical uptake of water by solid colloids like those in dry seeds. Carbon dioxide is primarily relevant for photosynthesis and respiration once the seed has already imbibed and initiated its metabolic processes.

72. (A) Concave and convex
Plasmolysis is classified based on the appearance of the shrinking protoplast. Concave plasmolysis occurs when the protoplast detaches only at certain points, leaving the plasma membrane with a curved, inward shape. This form is often reversible. Convex plasmolysis is more severe, where the protoplast completely detaches and rounds up into a spherical shape. This type is generally more damaging to the cell and may become irreversible if the membrane structure is compromised during the process.

73. (B) Wall pressure
Wall pressure is the mechanical force exerted by the rigid cell wall against the expanding protoplast. According to Newton's third law, it is equal and opposite to the turgor pressure. This pressure prevents the plant cell from bursting when placed in a hypotonic environment. The balance between turgor and wall pressure determines the final water potential of the cell. In a fully turgid cell, the wall pressure is at its maximum, counterbalancing the inward osmotic drive.

74. (B) Potential relative to pure water at standard STP
Thermodynamically, water potential is a measure of the free energy of water per unit volume compared to pure water under standard conditions. Pure water is assigned a potential of zero. The addition of solutes or the application of tension lowers this energy, making the potential negative. Pressure, on the other hand, usually increases it. Water potential is the fundamental driving force for water movement, as water always flows spontaneously from regions of higher to lower potential.

75. (A) I and III
Solute potential is always negative because the presence of solutes reduces the free energy of water. Matric potential is most significant in dry seeds or soils rather than in fully vacuolated mature cells, where it is often negligible. Pressure potential can indeed be positive, negative, or zero depending on the cell's state. Gravitational potential is usually only relevant in tall trees. Therefore, the claims that solute potential is positive and matric potential is significant in mature cells are incorrect.

76. (C) It is equal to osmotic pressure but with a negative sign.
Solute potential, also known as osmotic potential, represents the reduction in water potential due to dissolved solutes. It is numerically equal to the osmotic pressure of the solution but carries a negative value. As solute concentration increases, the solute potential becomes more negative. This component is a major factor in determining the direction of osmosis. It depends on both the number of solute particles and the absolute temperature, according to the van't Hoff equation.

77. (D) Negative (under tension)
In the xylem of a transpiring plant, water is pulled upward from the leaves, creating a state of tension. This tension corresponds to a negative pressure potential. This is a unique feature of the xylem, as most living cells maintain a positive pressure potential (turgor). This negative pressure is the driving force that allows water to be pulled from the soil through the plant and into the atmosphere. The magnitude of this tension increases with transpiration.

78. (C) Interaction with solid cellular surfaces
Matric potential is the component of water potential that accounts for the attraction between water molecules and solid, hydrophilic surfaces, such as cell walls or soil particles. These interactions, including hydrogen bonding and surface tension, reduce the free energy of the water. Matric potential is always negative and is particularly important in environments with low water content, such as dry soils or seeds. In well-watered, vacuolated plant cells, its contribution is generally considered negligible.

79. (B) A decrease in potential due to lowered solute levels
The addition of non-volatile solutes to pure water reduces the free energy of the water molecules. This occurs because the solute particles interact with water through hydration, decreasing the number of "free" water molecules available to do work. Consequently, the water potential of the solution becomes lower (more negative) than that of pure water. This reduction is represented by the solute potential component. This physical change is the basis for osmotic water movement into cells.

80. (B) -0.5 MPa
The water potential of a plant cell is calculated as the sum of its solute potential and its pressure potential. In this specific case, the calculation is -0.8 MPa plus 0.3 MPa, which equals -0.5 MPa. This total value determines the direction in which water will move relative to the cell's surroundings. If the surrounding water potential is higher than -0.5 MPa, water will enter the cell; if it is lower, water will leave.

81. (A) It is the dominant force driving water uptake in root hairs.
Gravitational potential is determined by the height of the water above a reference level and the acceleration due to gravity. While it is a significant factor in moving water to the tops of tall forest trees, it is not the dominant force for water uptake in root hairs. Uptake is primarily driven by the water potential gradient between the soil and the root. In small plants or at the cellular level, gravitational potential is typically negligible.

82. (C) Megapascals (MPa)
Water potential represents the potential energy of water per unit volume, which is equivalent to

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pressure. While older literature used units like atmospheres or bars, the standard International System (SI) unit in modern plant physiology is the Pascal. Due to the high pressures often encountered in plants, the Megapascal (MPa) is the most commonly used unit. One MPa is approximately equal to ten bars or nearly ten atmospheres of pressure.

83. (A) The maximum water potential, defined as zero
By convention, pure water at standard temperature and atmospheric pressure is assigned the maximum possible water potential value of zero. Any addition of solutes or the application of negative pressure (tension) will decrease this value, resulting in a negative water potential. Therefore, pure water always has a higher potential than any aqueous solution. This standard reference point allows scientists to quantify the thermodynamic state and movement of water in different parts of the soil-plant system.

84. (D) Both matric and gravitational potentials
In a typical mature, vacuolated parenchyma cell, the contribution of matric potential is minimal because the amount of water bound to surfaces is small compared to the free water in the vacuole. Similarly, gravitational potential is usually neglected at the scale of individual cells or small tissues because the height differences are insignificant. Therefore, the water potential equation is simplified to the sum of the solute and pressure potentials for most practical physiological calculations.

85. (A) I, II, III and V
Gravitational water drains under gravity, while capillary water in micropores is the main source for plants. Hygroscopic water is tightly bound and unavailable. The permanent wilting point is the state where plants cannot recover turgor. However, field capacity is not measured during rain; it is the water held after excess gravitational water has drained, usually two to three days after saturation. This timing allows the soil to reach a stable moisture state.

86. (C) After excess water has drained by gravity.
Field capacity is defined as the amount of water remaining in the soil after the excess gravitational water has drained away. This state is typically reached within two to three days after a heavy rain or irrigation event in well-drained soils. At field capacity, the soil micropores are filled with water, but the macropores contain air. This condition provides the optimal balance of water and oxygen for plant root growth and microbial activity.

87. (D) It is typically reached when soil water potential falls to approximately -1.5 MPa.
The permanent wilting point (PWP) is the moisture level at which the soil water potential is so low that the plant can no longer extract water. At this point, the plant wilts and cannot recover turgor even if placed in a humid environment, unless water is added to the soil. For many agricultural crops, PWP is conventionally accepted to occur at a soil water potential of about -1.5 MPa, representing a state of severe deficit.

88. (A) Capillary water
Soil water is classified into different types based on how it is held by soil particles. Gravitational water drains away too quickly for roots to absorb, while hygroscopic water is bound too tightly. Capillary water, which is held by surface tension in the small pores of the soil, is the only form that is readily available to plants. It exists as a liquid film around soil particles and can move toward roots through capillary action.

89. (B) Hygroscopic water is held at highly negative potentials; gravitational water drains too quickly.
The availability of soil water depends on its potential and its residence time. Gravitational water is not available because it moves through the soil profile under the force of gravity and drains away before roots can utilize it. In contrast, hygroscopic water is held so tightly to the surfaces of soil colloids by attractive forces that its water potential is extremely negative, far below what plant roots can exert to pull it away.

90. (B) Sand consists of macropores allowing rapid drainage.
Soil texture significantly influences water retention. Sandy soils are dominated by large particles and large spaces known as macropores. These macropores provide very little capillary force, allowing water to drain rapidly due to gravity. As a result, sand reaches field capacity at a much lower water content than clay. Clay soils have many more micropores that hold water against gravity through surface tension

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and adhesion, resulting in a higher capacity for storing plant-available water.

91. (A) Field capacity and permanent wilting point
Plant-available water is defined as the range of soil moisture that can actually be extracted by plant roots. It is mathematically calculated as the difference between the soil water content at field capacity and the water content at the permanent wilting point. Moisture above field capacity is lost to drainage, while moisture below the wilting point is held too tightly for uptake. Maximizing this range is a key goal in irrigation and soil management.

92. (C) Permanent wilting point is identical for all plant species regardless of their drought tolerance.
Soil moisture constants describe the water status at specific energy levels. Field capacity and the hygroscopic coefficient are defined by potential or humidity levels. However, the permanent wilting point is not a fixed physical constant for all plants. While -1.5 MPa is a common reference, different species and even cultivars have varying abilities to tolerate low potentials. Xerophytes, for example, can often continue to extract water at potentials much lower than those that would wilt typical mesophytes.

93. (D) Hygroscopic water
Hygroscopic water is the very thin film of water molecules that are adsorbed onto the surface of soil particles. This water is held by very strong electrostatic forces, resulting in an extremely low (negative) matric potential, often exceeding -31 MPa. At such high tensions, the water exists in a non-liquid state and is completely inaccessible to plant roots. This water remains even after capillary water has been exhausted and the plant has reached its permanent wilting point.

94. (C) -1.5 MPa
The permanent wilting point marks the lower limit of soil moisture availability for most agricultural crops. At this stage, the soil matric potential is significantly lower than that at field capacity. While the exact value can vary slightly depending on the plant and soil type, a matric potential of -1.5 MPa (or -15 bars) is the standard value used by agronomists to define the point of irreversible wilting for typical mesophytic species.

95. (C) A is true but R is false.
The pressure chamber, or Scholander bomb, is a standard tool for measuring the water potential of leaves or shoots. It works by applying external pressure to a leaf until xylem sap is forced back to the cut surface. This applied pressure is equal in magnitude to the original negative tension in the xylem. However, it does not measure solute potential by evaluating freezing point depression; that technique is known as osmometry. Therefore, the reason provided is incorrect.

96. (D) Water content relative to that at full turgor.
Relative Water Content (RWC) is a fundamental physiological measurement used to evaluate the water status of plant tissues. It expresses the current amount of water in a sample as a percentage of the total water the tissue could hold at its maximum turgidity. RWC is a better indicator of metabolic activity and stress than absolute water content because it accounts for differences in tissue structure. It is calculated using fresh, turgid, and dry weights.

97. (A) Measuring vapor pressure equilibrium with air.
Thermocouple psychrometry is a precise method for determining water potential based on the relationship between water potential and relative humidity. A tissue sample is sealed in a small chamber until the vapor pressure of the air reaches equilibrium with the water in the tissue. The psychrometer then measures either the wet-bulb depression or the dew point. This information allows for the calculation of the total water potential of the sample based on established thermodynamic principles.

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98. (C) -0.08 MPa due to column cavitation
Soil tensiometers are used to measure matric potential by using a water-filled tube with a porous ceramic tip. As the soil dries, it pulls water out of the tube, creating a vacuum that is measured by a gauge. However, tensiometers have a limited range. When the tension inside the tube exceeds approximately -0.08 MPa, the water column cavitates, forming air bubbles that break the hydraulic connection. This makes them unsuitable for measuring very dry soils.

99. (A) Fresh mass, turgid mass, and dry mass
To calculate the Relative Water Content (RWC), three specific mass measurements are required. First, the fresh mass is determined immediately

after sampling. Then, the tissue is soaked in water to reach its maximum turgidity, and the turgid mass is recorded. Finally, the tissue is oven-dried to find the dry mass. The formula subtracts the dry mass from both the fresh and turgid masses, expressing the ratio of the two resulting values as a percentage.

100. (D) Porometer - Soil moisture content
Various instruments are used in plant and soil science to monitor water status. Pressure chambers measure leaf potential, and psychrometers can evaluate both total and solute potentials. Tensiometers are dedicated to measuring soil matric potential. However, a porometer is an instrument used to measure the stomatal conductance or resistance of a leaf by tracking gas exchange. It is not used to determine soil moisture content, which is typically measured using gravimetric methods or sensors.

101. (B) Chamber estimates xylem tension; psychrometer measures vapor.
The pressure chamber and thermocouple psychrometer are both used to evaluate water potential but operate on different physical principles. The pressure chamber directly estimates the negative hydrostatic pressure (tension) existing in the xylem conduits. In contrast, the psychrometer measures the equilibrium vapor pressure above a tissue sample to calculate the total water potential. The chamber is often preferred for field use due to its portability, while psychrometers are typically used in controlled laboratory settings.

102. (C) Sap is forced back out of the cut surface.
When using a pressure chamber, the leaf is placed inside a sealed vessel with the cut end of the petiole protruding. As compressed gas is introduced, the external pressure pushes against the water within the cells. When this applied pressure exactly balances the tension that was pulling water away from the cut surface, a droplet of sap will appear at the petiole end. This "balancing pressure" is taken as the measure of the leaf's water potential.

103. (D) Chlorophyll fluorometer
To determine the water status of a plant, researchers use pressure bombs for potential, psychrometers for vapor pressure, and gravimetric methods for relative water content. These tools provide direct information about hydration and thermodynamic state. A chlorophyll fluorometer, however, is used to measure the efficiency of Photosystem II and the overall photosynthetic performance of the leaf. While water stress can affect fluorescence, it is not a direct tool for measuring water potential or content itself.

104. (A) Just before sunrise when potentials equilibrate.
Predawn leaf water potential is measured just before sunrise, a time when transpiration is minimal because the stomata have been closed overnight. During this period, the plant has had sufficient time to equilibrate its internal water potential with the soil water potential. Therefore, predawn measurements provide a very reliable proxy for the actual moisture status of the soil in the root zone. Measurements taken at other times are heavily influenced by the day's transpirational flux.

105. (A) P-3, Q-4, R-1, S-2
The apoplastic pathway involves water moving through the cell walls and intercellular spaces without entering the living protoplasm. The symplastic pathway uses the network of plasmodesmata to move water between adjacent cells. The transmembrane pathway involves water crossing successive plasma membranes. The Casparian strip is a suberized band in the endodermis that blocks the apoplastic route, forcing water to enter the symplast. These pathways together govern the movement of water from soil to xylem.

106. (B) Cell walls, intercellular spaces, and xylem vessels.
The apoplast is the non-living continuum in the plant body that consists of all the interconnected cell walls, the intercellular air spaces, and the interior of dead tracheary elements like xylem vessels and tracheids. Water and solutes can move through this system relatively freely by diffusion or bulk flow. It is separated from the symplast by the plasma membranes of the living cells. The apoplastic pathway offers the lowest resistance to water movement in the root cortex.

107. (A) Water must cross the plasma membrane at least once.
The symplastic pathway involves the movement of water and solutes through the interconnected cytoplasm of living cells. For water to enter this system from the soil or the apoplast, it must cross

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the plasma membrane of a cell, such as a root hair or epidermal cell. Once inside, it can travel from cell to cell through plasmodesmata. This pathway allows the plant to exercise metabolic control over the types and amounts of substances that are absorbed.

108. (C) Forcing apoplastic water to cross a membrane.
The Casparian strip is a localized thickening of suberin and lignin found in the radial and transverse walls of endodermal cells. This hydrophobic barrier effectively blocks the apoplastic movement of water and dissolved minerals into the stele. Consequently, all water and solutes must cross the plasma membrane of the endodermal cells to enter the symplastic pathway. This mechanism allows the plant to selectively regulate and filter the nutrients that reach the vascular tissue for long-distance transport.

109. (B) Two plasma membranes and the cell wall.
In the transmembrane pathway, water moves between cells by exiting one cell, crossing its plasma membrane and the intervening cell wall, and then entering the next cell through its plasma membrane. This process occurs sequentially as water moves across the root cortex. Unlike the symplastic route, it does not rely on plasmodesmata. The movement of water through this pathway is often facilitated by aquaporins, which are specialized channel proteins that increase the hydraulic conductivity of the membranes.

110. (C) The apoplastic continuum is broken at the stele.
The deposition of suberin in the endodermal cell walls creates the Casparian strip, which acts as an impermeable seal between the root cortex and the vascular cylinder. This interruption of the apoplastic continuum ensures that water and ions cannot bypass the living protoplasts of the endodermis. By breaking the apoplastic route, the plant can maintain a higher concentration of ions within the stele than in the surrounding cortex, which is essential for generating root pressure.

111. (B) Apoplastic pathway
During periods of high transpiration, water moves rapidly from the soil to the xylem. In the root cortex, the apoplastic pathway generally offers the lowest resistance to this flow. This is because water moves through the relatively porous matrix of the cell walls and intercellular spaces, avoiding the high-resistance barriers of the plasma membranes and the crowded cytoplasm. However, this apoplastic route is eventually blocked by the Casparian strip, forcing water into the symplastic pathway.

112. (B) The xylem vessels in the root possess functional Casparian strips.
Root hairs are indeed unicellular extensions of the epiblema that increase the surface area for absorption. The zone of maturation is the primary site where these hairs are found. The exodermis can also develop suberized bands in some species. However, xylem vessels are dead, hollow tubes designed for bulk flow and do not possess Casparian strips. The Casparian strip is a unique anatomical feature restricted to the walls of the living endodermal cells surrounding the stele.

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113. (D) Apoplastic pathway
The apoplastic pathway is the only route of water movement where water stays entirely within the non-living parts of the root, such as the cell walls and intercellular spaces. In this pathway, water does not cross any plasma membranes as it moves through the cortex toward the center of the root. This continues until it reaches the endodermis, where the Casparian strip blocks the way and finally forces the water to enter the symplastic system.

114. (A) Leakage of accumulated ions out of the stele.
The suberized endodermis acts as a one-way filter for nutrients. By blocking the apoplastic pathway, it prevents water and minerals from entering the stele without passing through a living membrane. Equally important, the Casparian strip prevents the ions that have been actively accumulated in the xylem from leaking back out into the root cortex. This maintenance of a high solute concentration in the stele is essential for creating the osmotic gradient that drives root pressure.

115. (B) II and III
Water uptake is driven by a potential gradient from the soil to the root, following thermodynamic laws. Aquaporins facilitate this movement across plasma membranes by providing low-resistance channels. However, while root pressure is a real phenomenon, it is generally insufficient to

push water to the tops of tall trees. Instead, the ascent of sap in tall plants is driven by the transpirational pull and the cohesive properties of water, rather than positive hydrostatic root pressure.

116. (C) Negative pressure pulling cohesive water.
The cohesion-tension theory is the most widely accepted explanation for the ascent of sap. It states that the evaporation of water from leaf mesophyll cells creates a highly negative water potential, which generates a pulling force (tension). Because water molecules are cohesive due to hydrogen bonding, this tension is transmitted down the xylem to the roots. This pull acts like a suction, drawing a continuous column of water upward through the plant against the force of gravity.

117. (A) Active ion accumulation lowering xylem potential.
Root pressure is a positive hydrostatic pressure that develops in the xylem of some plants, typically when transpiration is low and soil moisture is high. It is caused by the active transport of mineral ions into the xylem vessels. This accumulation of solutes lowers the water potential in the xylem, driving the osmotic entry of water from the surrounding root cells. The resulting pressure can force xylem sap upward, sometimes leading to the phenomenon of guttation.

118. (A) At night when stomata are closed and flow is low.
Hydraulic lift occurs when deep-rooted plants absorb water from moist, deep soil layers and transport it to the shallower, drier soil. This process typically happens at night when the plant's stomata are closed and the transpirational pull is nearly absent. During this time, the water potential of the roots in the dry upper soil layers becomes higher than that of the surrounding soil, causing water to leak out. This redistributed water can benefit neighboring plants.

119. (A) Sap freezing or column tension breaking.
Cavitation is the formation of gas or vapor bubbles within the xylem conduits, which breaks the continuity of the water column. It is often caused by extreme tension generated during high transpiration or by the freezing and thawing of xylem sap, which releases dissolved gases. These bubbles can expand to fill the vessel, a condition known as an embolism, which blocks the upward transport of water and significantly reduces the hydraulic conductivity of the vascular system.

120. (D) Root pressure can dissolve bubbles and refill.
While embolisms can severely restrict water transport, many plants possess mechanisms to recover. During the night or when transpiration is very low, positive root pressure can develop in the xylem. This positive pressure can force the air trapped in cavitated vessels back into solution, thereby refilling the conduit and restoring its hydraulic function. Some plants also use specialized parenchyma cells to actively secrete solutes into the vessels to draw water in and dissolve the trapped air bubbles.

121. (D) High root pressure and low transpiration.
Guttation is the exudation of liquid water from specialized structures called hydathodes, located at the leaf margins or tips. This phenomenon occurs when the soil is very moist and the air is humid, resulting in low transpirational water loss. Under these conditions, the positive root pressure developed in the xylem is strong enough to push water all the way up and out of the leaves. It is distinct from dew, which is atmospheric moisture that condenses.

122. (C) Atmospheric pressure pushing water from below is the primary driving force for sap ascent.
The ascent of sap is driven by the transpirational pull and the cohesive strength of water columns, which are strong enough to reach the tops of the tallest trees. Capillarity and atmospheric pressure contribute very little; atmospheric pressure can only support a water column of about 10 meters, which is far shorter than many trees. The cohesion-tension theory explains how water form a continuous column from the roots to the leaves and is pulled upward by negative pressure.

123. (A) Vessel elements are wider and more vulnerable.
Tracheary elements vary in their diameter and structure, which influences their susceptibility to cavitation. Vessel elements are generally wider than tracheids, which allows for more efficient water transport but also makes them more prone to the formation and spread of air bubbles. A single cavitation event can block a large volume of flow in a wide vessel. Tracheids, being narrower and having more restricted connections through

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pits, are more resistant to cavitation and help maintain transport safety.

124. (D) Active water transport by xylem parenchyma.
The maintenance of the xylem sap column is a physical process that relies on the cohesion between water molecules, the adhesion of water to the hydrophilic walls of the vessels, and the transpirational pull from the leaves. These forces allow water to move in bulk without the direct use of metabolic energy. While xylem parenchyma cells are living and involved in storage or lateral transport, they do not actively pump or transport water up the main vascular conduits.

125. (C) Only II
The driving force for the ascent of sap is indeed the negative water potential of the atmosphere. Xylem vessels also require thick walls to resist the inward pulling force of the tension. When transpiration is high, the negative pressure causes the xylem and the trunk to shrink slightly. However, the water columns in the xylem are maintained in a state of tension (negative pressure), not compression. Compression would involve a positive pressure pushing the molecules together.

126. (C) Microcapillary pores in pit membranes.
Pit membranes are modified primary walls and middle lamellae that separate adjacent xylem conduits. These membranes contain extremely small microcapillary pores. When a vessel cavitates and fills with air, the surface tension of the water within these tiny pores prevents the air from being sucked into the neighboring functional vessel. This "air-seeding" protection is crucial for isolating embolisms and ensuring that a single cavitation event does not cause a catastrophic failure of the entire vascular system.

127. (A) An electrical circuit with various potentials.
The Soil-Plant-Atmosphere Continuum (SPAC) model treats the movement of water through the entire environment as a single, integrated process. It is often described using an analog to an electrical circuit, following Ohm's Law. In this model, the water potential gradient represents the voltage, the rate of water flow represents the current, and the various tissues and boundary layers provide the resistances. This framework allows researchers to quantify and predict how water moves through the system.

128. (A) $\Psi_{soil} > \Psi_{root} > \Psi_{leaf} > \Psi_{atmosphere}$
Water movement through the Soil-Plant-Atmosphere Continuum is a spontaneous process driven by a decreasing gradient of water potential. For water to flow from the soil into the plant and then out into the air, the potential must be highest in the soil and lowest in the atmosphere. Typical values show a slight drop from soil to roots, a larger drop to the leaves, and an extremely large drop from the leaf to the dry outside air.

129. (C) Transpiration reduction and water conservation.
Stomata are the primary regulators of water loss in the SPAC system. According to the electrical analog, an increase in stomatal resistance represents a barrier to the flow of water vapor. This leads to an immediate reduction in the transpirational flux from the leaf to the atmosphere. By closing their stomata, plants can conserve internal water and prevent their leaf water potential from dropping to dangerous levels, especially during periods of soil water deficit or high atmospheric demand.

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130. (C) Regulate stomata to prevent pressure drops.
In arid environments, plants must carefully balance the need for carbon dioxide with the risk of excessive water loss. A key adaptation is the precise regulation of stomatal conductance. By closing stomata in response to dry soil or high air demand, the plant increases its resistance to water vapor diffusion. This regulation prevents the xylem tension from reaching a critical threshold that would cause widespread cavitation and the catastrophic failure of the plant's hydraulic system.

131. (C) The soil-root interface and contact loss.
As soil dries, its own hydraulic conductivity decreases dramatically because the remaining water is held in very small pores or as thin films. Furthermore, the roots may shrink as they lose turgor, causing them to pull away from the soil particles. This results in a significant increase in resistance at the soil-root interface. In many dry conditions, this interface resistance becomes the dominant bottleneck for water uptake, exceeding the resistance within the root or the xylem.

132. (C) Xylem resistance - Variable based on pumps.
Resistance in the SPAC is controlled by various factors. Boundary layer resistance depends on

wind speed and leaf morphology, while stomatal resistance is dynamically regulated by the turgor of guard cells. Cuticular resistance is generally high and relatively constant. However, xylem resistance is determined by the physical diameter and number of conduits and the occurrence of embolisms. It is not variable based on active metabolic pumps, as water movement in the xylem is a purely physical process.

133. (D) Phloem sucrose concentration
The Soil-Plant-Atmosphere Continuum (SPAC) focuses on the transport of water from the soil through the xylem and out into the air. Key parameters include the vapor pressure deficit of the air, the soil matric potential, and the physical resistance offered by xylem conduits. While phloem sucrose concentration is vital for the transport of photosynthates and for osmotic adjustments, it is not a direct component of the driving forces or resistances that govern the primary water flux.

134. (C) Stomatal and boundary layer resistance.
The largest drop in water potential in the entire SPAC occurs during the transition from liquid water inside the leaf to water vapor in the atmosphere. This phase change and subsequent diffusion are controlled by the resistances at the leaf surface. Stomatal resistance, which is biologically regulated, and boundary layer resistance, which is influenced by air movement, together act as the primary gatekeepers. These points of high resistance allow the plant to control its water loss and maintain hydration.

135. (A) I, II, III and IV
On a typical sunny day, water potential values follow a declining gradient through the SPAC. Soil potential might be near -0.1 MPa, with roots slightly lower at -0.5 MPa and leaves further down at -1.5 MPa. The atmosphere, especially when not saturated, has an extremely low potential, often reaching -100 MPa or less. These values drive the continuous flow of water. The claim that the atmosphere is at 0 MPa is incorrect, as that represents total saturation.

136. (C) Water vapor concentration gradients.
Water moves through the SPAC in both liquid and vapor phases. Within the soil, roots, and xylem, the movement is primarily liquid and is driven by gradients in hydrostatic pressure or water potential. However, once water evaporates into the air spaces of the leaf, its movement out through the stomata into the atmosphere occurs in the vapor phase. This diffusion is driven by the gradient in water vapor concentration (or vapor pressure) between the leaf and the air.

137. (B) Loss of water vapor from the aerial plant parts.
Transpiration is the physiological process by which plants lose water in the form of vapor through their aerial surfaces, primarily the leaves. It involves the evaporation of water from the moist cell walls of the mesophyll into the internal air spaces, followed by its diffusion through the stomata into the atmosphere. This process is essential for driving the ascent of sap, regulating leaf temperature through evaporative cooling, and facilitating the distribution of minerals throughout the plant.

138. (C) Stomatal transpiration
Plants can lose water through several pathways, including the cuticle, lenticels, and stomata. However, the majority of transpirational water loss in most mesophytic plants occurs through the stomatal pores. Stomatal transpiration typically accounts for 85% to 95% of the total water lost by a leaf. This pathway is of paramount importance because it is the only one that the plant can actively regulate by opening and closing the guard cells in response to various environmental signals.

139. (D) It continues even when stomata are fully closed.
Lenticels are small, porous openings found in the bark of woody stems and branches that allow for gas exchange. While the volume of water lost through lenticular transpiration is relatively small compared to stomatal loss, it is physiologically significant because it is a continuous process. Unlike stomata, lenticels cannot be closed. Therefore, lenticular transpiration continues day and night, even during periods of severe drought or when the plant is dormant and has shed its leaves.

140. (B) Latent heat loss dissipates solar radiation.
The leaf energy balance describes how incident solar radiation is dissipated to prevent lethal overheating. A large portion of the absorbed energy is used to convert liquid water into vapor during transpiration. This is known as latent heat loss. Because water has a high latent heat of

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vaporization, this process is extremely effective at cooling the leaf. Other mechanisms, such as sensible heat transfer to the air and long-wave radiation, also contribute, but transpiration is the primary biological regulator.

141. (B) Is subject to biological regulation via stomata.
Both evaporation and transpiration involve the phase change of water from liquid to vapor and the absorption of latent heat. However, evaporation from a free water surface is a purely physical process determined solely by environmental factors like temperature and wind. Transpiration, while also influenced by these factors, is a biological process that is strictly regulated by the plant. Through the movement of guard cells, the plant can adjust its stomatal conductance to optimize the trade-off between carbon gain and water loss.

142. (C) A significant increase in leaf temperature.
Transpiration serves as the primary cooling mechanism for leaves by dissipating absorbed solar energy as latent heat. If a plant in full sunlight has its stomata forced closed, this evaporative cooling stops immediately. As a result, the leaf cannot shed the thermal energy it is absorbing from the sun, leading to a rapid and significant increase in leaf temperature. This can cause the leaf to exceed its thermal tolerance, resulting in heat stress and damage to photosynthetic machinery.

143. (D) Its rate is under tight physiological control by specialized cuticular guard cells.
Cuticular transpiration involves the diffusion of water vapor directly through the epidermal cuticle. Its rate depends on the thickness and composition of the waxy layers, and it is usually higher in young leaves. While the cuticle provides a vital barrier, it does not possess any specialized cells like guard cells to actively regulate its permeability. Unlike stomatal transpiration, which is under tight biological control, cuticular water loss is largely a passive process governed by the physical properties of the wax.

144. (C) Cuticular transpiration dominates.
In a well-watered C3 plant, stomata typically close at night to prevent unnecessary water loss when photosynthesis is not possible. Although stomatal conductance drops to very low levels, the plant still loses some water. During these hours, cuticular transpiration becomes the dominant pathway for water loss. Although the rate is much lower than daytime stomatal transpiration, it is a continuous process that reflects the inherent permeability of the leaf's waxy surface even when the primary pores are sealed.

145. (A) Both A and R are true and R is the correct explanation of A.
The transition of water from the liquid phase on the surface of mesophyll cells to the vapor phase in the substomatal cavity is an endothermic process. It requires the input of energy to break the hydrogen bonds between water molecules. This energy, known as the latent heat of vaporization, is absorbed from the leaf tissue itself. As a result, the temperature of the leaf decreases. This cooling effect is essential for maintaining leaf temperatures within a range that is optimal for physiological and biochemical functions.

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146. (D) Casparian strip
Transpiration occurs through various aerial parts of the plant where water can escape into the atmosphere. The main pathways are the stomata on the leaf surface, the lenticels on woody stems, and directly through the waxy cuticle of the epidermis. The Casparian strip, however, is an internal anatomical feature located in the root endodermis. Its function is to block the apoplastic movement of water and solutes into the vascular cylinder, and it is not a pathway for transpirational water loss.

147. (B) Latent heat (λE)
In the context of the leaf energy budget, different terms represent the various ways energy is exchanged with the environment. Sensible heat (H) refers to heat transfer by convection and conduction, while net radiation (R_n) is the total energy absorbed. The specific term for the energy used in the phase change of water during transpiration is latent heat (λE). This term accounts for the large amount of thermal energy dissipated as liquid water vaporizes, which provides the cooling effect essential for plant survival.

148. (D) Kidney-shaped (reniform)
In typical dicotyledonous plants, the stomata are composed of two specialized epidermal cells known as guard cells. These cells have

a characteristic kidney-shaped or reniform appearance. They are joined at their ends, and the space between them forms the stomatal pore. This specific morphology, combined with the differential thickening of their cell walls, allows the cells to curve outward when they become turgid, thereby increasing the size of the pore for gas exchange and transpiration.

149. (A) Provide a reservoir of ions for movements.
Subsidiary cells are specialized epidermal cells that surround the guard cells in many plant species. Their primary physiological role is to act as a reservoir for water and ions, particularly potassium and chloride, which move in and out of the guard cells during stomatal opening and closing. They also provide mechanical support and help facilitate the rapid changes in turgor required for stomatal movement. This functional coordination between guard and subsidiary cells is known as the stomatal complex.

150. (D) Radial micellation causes cell elongation.
The cell walls of guard cells contain cellulose microfibrils that are arranged in a specific radial pattern, a feature known as radial micellation. These microfibrils act like inelastic hoops around the cell. When turgor pressure increases, the microfibrils prevent the cell from expanding much in width. Instead, they force the guard cell to expand primarily in length. Because the ends of the cells are fixed, this elongation causes the cells to curve outward, which opens the stomatal pore.

151. (A) Dumbbell-shaped with bulbous, thin ends.
Grasses and many other monocots possess a unique stomatal architecture. Their guard cells are dumbbell-shaped or bone-shaped rather than kidney-shaped. These cells have bulbous, thin-walled ends and a narrow, thick-walled middle section. When turgor increases, the bulbous ends swell and push against each other, which forces the middle sections apart and opens the pore. This specialized structure allows for very rapid stomatal movements, which may contribute to the higher water use efficiency often observed in these species.

152. (C) Curve outward, opening the pore.
The opening of dicot stomata is a result of the unique mechanical properties of the guard cell walls. The ventral wall, which faces the pore, is significantly thicker and less elastic than the dorsal wall, which faces away. When water enters the guard cells and turgor pressure rises, the thin dorsal wall stretches and expands much more than the thick ventral wall. This uneven expansion, combined with radial micellation, causes the guard cells to bow or curve outward, opening the stomatal aperture.

153. (D) Hypostomatic leaves are in aquatic plants.
Stomatal distribution is adapted to the plant's environment. Epistomatic leaves have stomata only on the upper surface, which is common in floating aquatic plants like water lilies. Hypostomatic leaves, with stomata only on the lower surface, are common in many terrestrial trees to reduce water loss. Amphistomatic leaves have stomata on both sides. The claim that hypostomatic leaves are characteristic of aquatic plants is incorrect, as these plants typically require upper stomata for gas exchange while in contact with air.

154. (B) Grasses and crops like maize.
Amphistomatic leaves, which possess stomata on both the upper and lower epidermal surfaces, are designed to maximize the rate of gas exchange. This distribution is most common in fast-growing plants and those that inhabit environments with high light intensity, such as many grasses and agricultural crops like maize and wheat. Having stomata on both sides reduces the diffusion distance for carbon dioxide to reach the mesophyll cells, supporting higher rates of photosynthesis needed for rapid biomass production.

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155. (A) P-2, Q-4, R-1, S-3
Hypostomatic leaves (Apple type) have stomata restricted to the lower surface. Some amphistomatic leaves (Potato type) have them on both surfaces but with a higher frequency on the lower side. Others (Oat type) have a nearly equal distribution on both surfaces. Epistomatic leaves (Water lily type) have stomata only on the upper surface to facilitate gas exchange with the atmosphere while floating on water. These patterns represent evolutionary adaptations to optimize photosynthesis while minimizing excessive transpirational water loss.

156. (B) Requirement of radial micellation for opening.
Despite the morphological differences between kidney-shaped dicot guard cells and dumbbell-shaped monocot guard cells, they share the same

fundamental mechanical principle for opening. In both types, the cellulose microfibrils are oriented radially (radial micellation). This arrangement ensures that an increase in turgor pressure leads to a change in cell shape that opens the pore, rather than a uniform swelling of the entire cell. This specific structural orientation is essential for the regulated movement of stomata in all higher plants.

157. (C) Absence of mitochondria
Functional guard cells are characterized by several unique features that enable their movement, including the presence of chloroplasts and the radial orientation of cellulose microfibrils. They also have unevenly thickened cell walls that facilitate curving. However, guard cells are metabolically very active and require a significant amount of ATP to drive the proton pumps necessary for ion transport. Therefore, they possess functional mitochondria to provide the energy needed for these processes. The claim that they lack mitochondria is incorrect.

158. (A) Guard cell turgor pressure
The size of the stomatal aperture is directly controlled by the turgor pressure of the guard cells. When water enters these cells through osmosis, their turgor pressure increases, causing them to expand and curve outward due to their specialized wall structure. This movement pulls the pore open. Conversely, when guard cells lose water, their turgor drops, and they become flaccid, allowing the pore to close. This dynamic regulation is the primary mechanism by which plants control gas exchange and transpiration.

159. (B) Levitt and Fujino
The active potassium-ion (K^+) pump hypothesis is the most widely accepted modern theory for stomatal movement. It was primarily developed and elaborated by scientists like Fujino and Levitt. The theory explains that stomatal opening is initiated by the active uptake of potassium ions into the guard cells from the surrounding epidermal cells. This influx lowers the osmotic potential, driving water entry and increasing turgor. This discovery replaced earlier theories that focused solely on starch-sugar interconversion or simple changes in pH.

160. (A) Malate balances the influx of K^+ ions.
During stomatal opening, the massive influx of positively charged potassium ions into the guard cells must be electrically balanced to maintain cellular homeostasis. This is achieved in part by the accumulation of negatively charged anions. While chloride ions are often used, many plants also synthesize malate, a divalent organic anion, through the breakdown of starch. Malate serves both as an osmoticum to further lower the water potential and as a counter-ion to balance the charge of the accumulated potassium.

161. (A) Starch to sugar conversion opens stomata.
The starch-sugar interconversion theory suggests that changes in the pH of the guard cells influence enzyme activity. During the day, photosynthesis reduces the concentration of carbon dioxide, which increases the internal pH. This higher pH favors the activity of phosphorylase enzymes that convert insoluble starch into soluble sugars. The increase in sugar concentration lowers the osmotic potential of the guard cells, leading to water influx, increased turgor, and the opening of the stomatal pore.

162. (D) Proton efflux via plasma membrane ATPase.
Stomatal opening begins with the activation of plasma membrane H^+-ATPases in the guard cells. These pumps use ATP to actively transport protons out of the cell, creating an electrochemical gradient and hyperpolarizing the membrane. This hyperpolarization triggers the opening of voltage-gated inward-rectifying potassium channels, allowing K^+ to flow into the cell. This proton efflux is the fundamental active step that drives the subsequent passive accumulation of ions and water, leading to increased turgor and pore opening.

163. (B) The proton pump requires a supply of ATP.
The fact that inhibitors of ATP synthesis prevent stomatal opening proves that the process is energy-dependent. The plasma membrane H^+ -ATPase, which is the primary driver of the ion fluxes needed for opening, requires a constant supply of ATP to function. This ATP is provided by both photophosphorylation in the guard cell chloroplasts and oxidative phosphorylation in the mitochondria. Without metabolic energy, the plant cannot maintain the proton gradient necessary to accumulate the solutes that drive water entry and turgor.

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164. (D) Water enters the guard cells exosmotically from the subsidiary cells.
Stomatal opening involves several coordinated ion and water movements. Potassium and chloride ions enter the guard cells, which significantly lowers their solute and water potential. This creates a gradient that causes water to move into the guard cells from the surrounding subsidiary or epidermal cells. However, this movement is endosmotic, not exosmotic. Exosmosis refers to the movement of water out of a cell. During opening, water must enter the guard cells to increase their turgor and open the pore.

165. (A) H^+ efflux → Hyperpolarization → K^+ influx → Decrease in Ψ_s → Water influx → Increased turgor
Stomatal opening follows a precise sequence of physiological events. It begins with the active efflux of protons, which hyperpolarizes the plasma membrane. This change in membrane potential activates inward-rectifying potassium channels, leading to a massive influx of K^+ ions. The accumulation of these ions, along with anions, decreases the solute potential of the guard cell. This draws water into the cell via osmosis, increasing turgor pressure and causing the guard cells to curve outward and open the pore.

166. (D) Closing
Stomatal closing is a highly regulated process that is almost the reverse of opening. A key step in closing, especially when triggered by ABA, is the activation of anion channels like SLAC1. These channels allow negatively charged ions, such as malate and chloride, to exit the guard cell. This efflux depolarizes the plasma membrane, which then triggers the opening of outward-rectifying potassium channels. The resulting loss of solutes leads to water exit, decreased turgor, and the closure of the stomatal pore.

167. (D) Efflux of potassium and chloride ions.
Stomatal opening is promoted by events that increase the solute concentration and turgor of the guard cells, such as the activation of proton pumps, the accumulation of malate, and the breakdown of starch into sugars. These processes all lead to water influx. In contrast, the efflux of potassium and chloride ions reduces the solute concentration inside the guard cells. This leads to the loss of water and a decrease in turgor, which are the primary events that cause stomatal closure, not opening.

168. (A) Blue light
Guard cells are uniquely sensitive to blue light, which triggers a rapid stomatal opening response that is independent of the photosynthetic rate. This response is mediated by specialized blue-light photoreceptors called phototropins. When activated, these receptors stimulate the plasma membrane H^+-ATPase, leading to proton efflux and the subsequent accumulation of potassium ions. This high sensitivity to blue light allows plants to rapidly open their stomata at dawn, even when light levels are low, to maximize early-morning carbon gain.

169. (A) Moisture the air can hold at saturation.
Vapor Pressure Deficit (VPD) is a critical environmental parameter that measures the drying power of the air. It is defined as the difference between the actual amount of moisture in the air and the total amount of moisture that the air can hold when it is completely saturated at a given temperature. A high VPD indicates dry air and a steep gradient for evaporation, which increases the transpirational driving force. It is a major factor influencing stomatal behavior and plant water stress.

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170. (D) Binding triggers calcium and opens channels.
Abscisic acid (ABA) is the primary hormone that signals water stress and triggers stomatal closure. When ABA binds to its receptors in the guard cell, it initiates a complex signaling cascade that leads to an increase in the concentration of cytosolic calcium ions. This calcium serves as a second messenger that activates anion and outward-rectifying potassium channels while inhibiting the proton pump. The resulting efflux of solutes leads to water loss, reduced turgor, and rapid closure of the stomatal pore.

171. (A) Stomatal closure
Stomatal behavior is highly sensitive to the concentration of carbon dioxide within the leaf's internal air spaces. When the internal CO_2 concentration increases—due to reduced photosynthesis or high atmospheric levels—the guard cells respond by closing the stomata. This response helps the plant avoid excessive water loss when it has an ample supply of carbon for its metabolic needs. Conversely, low internal

CO_2 levels typically act as a signal to open the stomata to facilitate more carbon uptake.

172. (C) Blue (400-500 nm)
Phototropins (phot1 and phot2) are the primary photoreceptors that mediate various plant responses to light, including the blue-light-induced opening of stomata. These flavoprotein receptors absorb light specifically in the blue and ultraviolet-A regions of the spectrum, which corresponds to wavelengths between 400 and 500 nm. Upon absorbing blue light, phototropins undergo autophosphorylation and initiate a signaling pathway that activates the proton pumps in the guard cell membrane, leading to ion influx and the subsequent opening of the stomatal pore.

173. (C) $Ca^{\{2+\}}$`
Calcium ions ($Ca^{\{2+\}}$) play a central role as a ubiquitous intracellular second messenger in the regulation of stomatal closure. When a plant experiences water stress, the hormone ABA triggers the release of calcium from internal stores into the guard cell cytosol. The elevated calcium levels then coordinate the opening of anion channels and the inhibition of inward-rectifying potassium channels and proton pumps. This integration of signals leads to the rapid efflux of solutes and the loss of turgor required to close the stomata.

174. (D) High CO_2 forces stomata to open widely.
Stomatal regulation is influenced by several environmental factors. High humidity (low VPD) and light typically favor opening, while low water potential and high ABA levels trigger closure. However, high concentrations of carbon dioxide, whether inside the leaf or in the atmosphere, generally act as a signal for stomatal closure, not opening. This is a mechanism by which the plant optimizes water use efficiency by reducing conductance when carbon is plentiful, preventing unnecessary water loss through transpiration.

175. (A) II, IV, I, III
The ABA-induced stomatal closure cascade follows a specific order of events. It begins when ABA binds to its receptors, such as those in the PYR/PYL family. This binding leads to the production of reactive oxygen species and a significant elevation of cytosolic calcium levels. These signals then activate outward-rectifying potassium and anion channels, facilitating the efflux of solutes from the guard cell. Finally, the resulting loss of water leads to a decrease in guard cell turgor and the closure of the pore.

176. (A) Blue light is more effective than red light.
Both red and blue light can stimulate stomatal opening, but they operate through different mechanisms. Red light drives opening primarily by providing energy for photosynthesis in the guard cell and mesophyll, which reduces internal carbon dioxide levels. Blue light, however, is significantly more effective because it also activates a specific blue-light-sensitive signaling pathway mediated by phototropin receptors. This additional stimulation of the proton pump allows blue light to produce a larger stomatal opening response at much lower intensities.

177. (C) Exposure to high intensity blue light
Stomatal closure is typically triggered by conditions that threaten the plant's water status, such as soil water deficit, high atmospheric CO_2, or high levels of the stress hormone ABA. In contrast, exposure to high-intensity blue light is a strong signal for stomatal opening. Blue light activates the specific phototropin-mediated signaling pathway that stimulates proton efflux and ion accumulation in the guard cells. This response allows the plant to maximize its gas exchange during periods of high light availability.

178. (A) The one-sided leaf area per unit ground area.
Leaf Area Index (LAI) is a dimensionless metric used in ecology and agronomy to quantify the amount of foliage in a plant canopy. It is defined as the total one-sided green leaf area of the canopy per unit of ground surface area below it. LAI is a key parameter for modeling light interception, photosynthesis, and transpiration at the ecosystem or field scale. An LAI of 3, for example, means there are 3 square meters of leaf for every square meter of ground.

179. (A) Rate is inversely proportional to humidity.
Relative humidity affects the transpiration rate by altering the vapor pressure gradient between the inside of the leaf and the surrounding air. When humidity is high, the air is nearly saturated with water, which reduces the gradient and slows the diffusion of water vapor out of the stomata. Conversely, when humidity is low, the air is dry and the gradient is steep, leading to a much faster rate of transpiration. Therefore, the

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rate of water loss is inversely proportional to the atmospheric humidity.

180. (A) Sweeping away the boundary layer of air.
Even in still air, a layer of moist, stagnant air called the boundary layer forms over the leaf surface. This layer increases the resistance to water vapor diffusion. A moderate increase in wind speed increases the transpiration rate by sweeping away this humid boundary layer and replacing it with drier ambient air. This reduces the total resistance and steepens the vapor pressure gradient from the leaf to the atmosphere. However, very high winds may eventually trigger stomatal closure due to mechanical stress.

181. (A) Increase resistance to water vapor diffusion.
Plants in windy and arid environments often possess morphological adaptations like dense hairs (trichomes) or recessed stomata. These features serve to trap a thicker layer of still, humid air near the leaf surface, effectively increasing the thickness of the boundary layer. This increased boundary layer resistance reduces the rate of water vapor diffusion out of the leaf, even when the ambient air is dry and windy. This is a vital strategy for conserving water and preventing dehydration in harsh climates.

182. (A) Increase, providing a driving force for flow.
As air temperature increases, the saturation vapor pressure—the maximum amount of water the air can hold—increases exponentially. Even if the absolute amount of moisture remains the same, the relative humidity drops, and the vapor pressure deficit (VPD) increases significantly. This larger deficit creates a much steeper gradient for evaporation, which increases the driving force for transpiration. This relationship explains why plants lose water much more rapidly on hot days than on cool days, assuming other factors remain constant.

183. (D) High stomatal frequency reduces water loss.
Plants utilize various structural adaptations to limit excessive transpiration, such as developing a thick waxy cuticle, curling their leaves to reduce surface area, and having sunken stomata that increase the diffusion path. However, a high frequency of stomata generally increases the potential for water loss, as there are more openings for vapor to escape. Xerophytes often have a lower number of stomata per unit area or restricted distributions on the leaf surface as a strategy to minimize their total transpirational flux.

184. (D) Trapping still air to increase resistance.
Trichomes, or leaf hairs, are a common adaptation for reducing water loss in plants. They function by creating a microenvironment of still, humid air right at the leaf surface. This trapped air layer increases the total boundary layer resistance, which slows the diffusion of water vapor from the stomata into the drier ambient atmosphere. In addition to reducing transpiration, trichomes can also reflect solar radiation, helping to keep the leaf temperature lower and further reducing the evaporative demand on the plant.

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185. (A) Both A and R are true and R is the correct explanation of A.
Many xerophytes, such as conifers and succulents, have stomata that are located in pits or deep crypts below the level of the epidermis. These sunken stomata are an effective adaptation for reducing transpiration. By placing the pore in a sheltered cavity, the plant increases the distance water vapor must diffuse to reach the outside air. Furthermore, the pit protects the pore from the desiccating effects of wind. Because the structural description and the physiological explanation are both accurate, the assertion and reason are true.

186. (A) Much greater at 20% RH
The driving force for transpiration is the difference in vapor pressure between the moist interior of the leaf and the outside air. At a constant temperature, a lower relative humidity corresponds to a much lower atmospheric vapor pressure and a larger vapor pressure deficit (VPD). Therefore, air at 20% relative humidity provides a much steeper gradient and a greater driving force for water loss than air at 80% relative humidity. This explains why transpiration rates are much higher in dry climates.

187. (C) High atmospheric relative humidity
Transpiration is influenced by several micrometeorological factors. High solar radiation provides energy for evaporation and opens stomata, while high temperatures and moderate wind speeds increase the vapor pressure gradient and reduce boundary layer resistance. In contrast, high relative humidity means the air is already close to saturation, which reduces the vapor pressure deficit. This smaller

gradient significantly slows the rate of water vapor diffusion out of the leaf. Therefore, high humidity acts to decrease, rather than increase, the transpiration rate.

188. (A) Reducing water loss from the plant
An antitranspirant is any substance or material that is applied to the aerial parts of a plant, primarily the leaves, with the specific purpose of reducing the amount of water lost through transpiration. These materials can work by forming a physical barrier, reflecting light, or chemically inducing stomatal closure. The use of antitranspirants is particularly important in agriculture and horticulture for helping plants survive dry periods, reducing irrigation requirements, and improving the success rate of transplants in stressful environments.

189. (C) Inducing partial stomatal closure
Phenylmercuric acetate (PMA) belongs to the category of metabolic antitranspirants. When applied to the leaves at low, non-toxic concentrations, it interferes with the metabolic processes that maintain guard cell turgor. Specifically, it can inhibit the activity of the proton pumps or interfere with ion transport, which leads to the partial closure of the stomatal pores. By reducing the stomatal aperture, PMA effectively increases the resistance to water vapor diffusion and lowers the overall rate of transpiration from the plant surface.

190. (A) Use of plastics or waxes to block stomata.
Film-forming antitranspirants are materials such as specialized waxes, plastics, or silicone emulsions that are sprayed onto the leaf surface. Upon drying, they form a thin, colorless, and relatively impermeable layer that covers the stomata and the cuticle. This physical film acts as a barrier that significantly reduces the escape of water vapor. While effective at conserving water, these films often have the disadvantage of also blocking the entry of carbon dioxide, which can severely limit the rate of photosynthesis.

191. (A) Increase leaf albedo, reducing temperature.
Kaolin is a white, inert clay mineral that is used as a reflectant antitranspirant. When sprayed on crops, it forms a white coating that increases the leaf's albedo, or its ability to reflect incident solar radiation. By reflecting a larger portion of the light, kaolin reduces the amount of energy absorbed by the leaf, thereby lowering the leaf temperature. A cooler leaf has a lower internal vapor pressure, which reduces the driving force for transpiration and helps the plant conserve water.

192. (D) Rapid stomatal closure via ion flux shifts.
Abscisic acid (ABA) is the natural "stress hormone" that plants produce to regulate their water status. When applied exogenously as an antitranspirant, ABA mimics this natural response. It binds to receptors on the guard cells and triggers a signaling cascade that causes the efflux of potassium and other solutes. The resulting loss of turgor leads to the rapid closure of the stomata. This chemical regulation is a highly effective way to reduce transpiration without applying a physical coating to the leaf surface.

193. (D) Film-forming compounds
While all antitranspirants aim to reduce water loss, film-forming compounds often present a major drawback for plant growth. These materials create a physical barrier that is not selectively permeable; it blocks the diffusion of carbon dioxide as much as, or sometimes even more than, it blocks water vapor. Because photosynthesis depends on the entry of CO_2 through the stomata, these films can cause a significant decline in the assimilation rate and final biomass production of the crop if applied too heavily.

194. (B) They provide a permanent, lifelong solution to drought stress with a single application.
Antitranspirants are useful tools for managing water stress in high-value crops and transplants. However, they are not a permanent solution. Physical films can crack or be washed away by rain, and metabolic closers like PMA or ABA are eventually degraded by the plant or diluted as the leaf grows. To be effective during a prolonged dry period, these materials must be reapplied periodically. Furthermore, they always involve a trade-off with photosynthesis, so they are not suitable for all growth stages.

195. (A) P-2, Q-3, R-1, S-4
Kaolin is a reflective material used to increase albedo. Abscisic acid is the natural endogenous hormone that triggers stomatal closure. Silicone emulsions form physical films that block water vapor diffusion. Phenylmercuric acetate is an exogenous chemical that metabolicly induces

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stomatal closure at low concentrations. Each of these materials utilizes a different physiological or physical mechanism to reduce the rate of transpirational water loss from the plant, making them suitable for different agricultural and horticultural applications.

196. (B) Reflectant antitranspirants
Reflectant antitranspirants, such as kaolin, work by reducing the leaf temperature and the vapor pressure gradient, rather than by creating a physical barrier over the stomatal pores. Therefore, they are less likely than film-forming types to severely interfere with the diffusion of carbon dioxide into the leaf. While they may slightly reduce the amount of light available for photosynthesis, they generally allow for better gas exchange than films that physically seal the openings, making them a more favorable option for many crops.

197. (D) Waxy emulsions
Reflectant antitranspirants are materials that increase the reflectivity of the leaf surface to reduce heat absorption. Common examples include kaolin clay, calcium carbonate, and diatomaceous earth, all of which leave a white residue that increases albedo. In contrast, waxy emulsions are classified as film-forming antitranspirants. They create a thin, colorless physical coating that blocks the stomatal pores and increases the resistance to vapor diffusion. They do not work by reflecting light but by physically sealing the transpirational pathways.

198. (A) Biomass produced to water transpired.
Water Use Efficiency (WUE) is a fundamental metric used to evaluate how effectively a plant utilizes water for growth. At the whole-plant or crop level, it is typically defined as the ratio of the total dry biomass produced (or grain yield) to the total amount of water lost through transpiration over the same period. A higher WUE indicates that the plant is able to fix more carbon and produce more tissue for every unit of water it spends, a key trait for drought resistance.

199. (D) TR is the inverse of Water Use Efficiency.
The Transpiration Ratio (TR) is another common way to express the relationship between water loss and productivity. It is defined as the total amount of water transpired by a plant divided by the amount of dry matter produced. Mathematically, the Transpiration Ratio is simply the inverse of the Water Use Efficiency. While WUE focuses on biomass gained per unit of water, TR focuses on the amount of water required to produce a unit of biomass. Both metrics provide essentially the same information.

200. (A) Instantaneous is $\frac{A}{E}$; intrinsic is $\frac{A}{g_s}$.
Instantaneous WUE and intrinsic WUE are two related but distinct physiological metrics. Instantaneous WUE is the ratio of net carbon assimilation (A) to the transpiration rate (E). It is directly influenced by the environmental vapor pressure deficit. Intrinsic WUE, however, is the ratio of net assimilation to stomatal conductance (g_s). This metric is a better indicator of the plant's own biological efficiency because it removes the direct effect of the air's drying power, focusing instead on the stomatal control of gas exchange.

201. (B) Opening stomata at night when VPD is low.
Crassulacean Acid Metabolism (CAM) plants exhibit the highest Water Use Efficiency among all photosynthetic types. This is because they have evolved to open their stomata at night to absorb carbon dioxide and store it as organic acids. During the night, the air temperature is lower and the relative humidity is higher, resulting in a much lower vapor pressure deficit (VPD) than during the day. By fixing carbon when the drying power of the air is minimal, CAM plants dramatically reduce their transpirational water loss.

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202. (A) High photosynthesis at low CO_2 concentrations.
C4 plants are significantly more water-efficient than C3 plants. This is because their specialized anatomy and the use of the enzyme PEP carboxylase allow them to concentrate carbon dioxide near the Rubisco enzyme. This CO_2-concentrating mechanism enables C4 plants to maintain high rates of photosynthesis even when their stomata are only partially open. By operating at a lower stomatal conductance while still fixing carbon effectively, C4 plants can produce a large amount of biomass with relatively little transpirational water loss.

203. (D) C4 plants - 800 to 1000
The Transpiration Ratio measures the moles of water transpired per mole of CO_2 fixed. CAM plants are the most efficient, with ratios between

50 and 100. C4 plants follow with ratios typically between 250 and 300, while C3 plants are the least efficient, often losing 400 to 500 moles of water. The claim that C4 plants have a ratio of 800 to 1000 is incorrect, as such high values would indicate very poor water use efficiency, which is the opposite of the C4 trait.

204. (A) Temporal separation of CO_2 uptake and fixation.
The remarkable water use efficiency of CAM plants is a direct consequence of their temporal separation of carbon acquisition and final fixation. By taking up carbon dioxide at night and storing it as malate, they can keep their stomata closed during the heat of the day. This allows the final fixation of carbon by Rubisco to occur in a high-CO_2 environment inside the leaf while the plant is sealed against transpirational loss. This strategy is an essential evolutionary adaptation for survival in extremely arid environments.

205. (B) C4, because PEP carboxylase suppresses photorespiration.
Under high light and high temperature conditions, C4 plants maintain a superior Water Use Efficiency compared to C3 plants. This is because C4 plants use PEP carboxylase to initially fix carbon, which has a much higher affinity for CO_2 and does not react with oxygen. This allows C4 plants to suppress photorespiration and maintain high carbon gain even with smaller stomatal apertures. In contrast, C3 plants suffer from increased photorespiration and must keep their stomata open wider, resulting in more water loss.

206. (C) Root nodule count
Instantaneous Water Use Efficiency is measured at the leaf level using gas exchange techniques. It is calculated by dividing the net assimilation rate of CO_2 by the transpiration rate. Factors that influence these rates, such as boundary layer resistance and stomatal conductance, are directly involved in the measurement. However, the number of root nodules is a parameter related to nitrogen fixation and root architecture. While it may indirectly affect plant health, it is not a direct variable in the mathematical calculation of leaf-level instantaneous WUE.

207. (A) The ratio of net CO_2 assimilation to conductance.
Intrinsic Water Use Efficiency (WUE_i) is a physiological metric that evaluates the efficiency of the plant's gas exchange independent of environmental demand. It is defined as the ratio of the net CO_2 assimilation rate (A) to the stomatal conductance (g_s). By using conductance instead of the transpiration rate, this metric focuses on the plant's biological regulation of the stomatal pore. It is a highly useful parameter in breeding and research for identifying genotypes that can maintain high carbon gain with minimal stomatal opening.

208. (C) C3
Among the three major photosynthetic pathways, C3 plants inherently possess the lowest Water Use Efficiency. This is primarily because they lack a mechanism to concentrate carbon dioxide around the Rubisco enzyme. To maintain a sufficient internal CO_2 concentration for photosynthesis, C3 plants must keep their stomata relatively open. This results in a high rate of transpirational water loss compared to the amount of carbon fixed. Both C4 and CAM plants have evolved specialized mechanisms to concentrate CO_2, allowing them to be much more water-efficient.

209. (B) ${}^{\{12\}}C$ over ${}^{\{13\}}C$ by the enzyme Rubisco.
Carbon isotope discrimination occurs because the enzyme Rubisco has a natural preference for the lighter ${}^{\{12\}}C$ isotope over the heavier ${}^{\{13\}}C$ isotope during carbon fixation. In C3 plants, when stomata are wide open, Rubisco can easily discriminate against the heavier molecule, resulting in a low ratio of ${}^{\{13\}}C$ to ${}^{\{12\}}C$ in the plant tissue. This discrimination provides a long-term, integrated measure of the internal CO_2 concentration and, by extension, the water use efficiency of the plant over the growing season.

210. (A) Low values indicate closed stomata and high WUE.
In C3 plants, carbon isotope discrimination ($\Delta^{13}C$) is inversely related to water use efficiency. When stomata are partially closed to conserve water (high WUE), the internal concentration of CO_2 decreases. This forces the Rubisco enzyme to fix a higher proportion of the heavier ${}^{\{13\}}C$ isotopes than it would if CO_2 were plentiful. As a result, plants with a more efficient water use strategy show less discrimination and have

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lower $\Delta^{13}C$ values. This makes isotope analysis a powerful tool for screening drought-resistant crop varieties.

211. (A) Instantaneous CO_2 assimilation and transpiration.
Infrared gas exchange analyzers (IRGA) are essential tools in plant physiology for measuring the dynamic exchange of gases between a leaf and its environment. These instruments precisely quantify the changes in the concentrations of carbon dioxide and water vapor in a sample chamber. By measuring these values, researchers can directly calculate the leaf's instantaneous rate of net CO_2 assimilation and its rate of transpiration. This information is critical for evaluating the physiological response of different breeding lines to environmental stresses like drought or heat.

212. (A) Weight changes of soil-plant systems for loss.
Lysimetry is a technique used to measure the total water loss from a soil-plant system through evapotranspiration. Whole-plant lysimeters consist of large containers filled with soil and the growing plant, which are placed on highly sensitive weighing scales. By continuously tracking the changes in the weight of the system and accounting for any added water, researchers can accurately determine the amount of water lost over time. This data is essential for calculating the whole-plant water use efficiency and for developing precise irrigation schedules.

213. (B) Fix a higher proportion of heavier $^{\{13\}}CO_2$ molecules.
When a plant keeps its stomata partially closed to achieve high water use efficiency, the rate of CO_2 supply to the chloroplast is reduced. As the internal CO_2 concentration drops, the Rubisco enzyme becomes less able to exercise its natural preference for the lighter $^{\{12\}}C$ isotope. Consequently, it is forced to fix a higher proportion of the heavier $^{\{13\}}C$ molecules that are present in the leaf air spaces. This leads to a higher concentration of $^{\{13\}}C$ in the plant's biomass, which is reflected in a lower discrimination value.

214. (B) Tillage practices that reduce the soil evaporation.
Agronomic strategies to improve field-level water use efficiency focus on maximizing the amount of water used for transpiration while minimizing losses to evaporation and runoff. Conservation tillage and mulching are effective practices because they keep the soil surface covered, which significantly reduces the direct evaporation of water from the soil. These methods help maintain soil moisture for a longer period, allowing the crop to utilize the available water more efficiently for biomass production and yield during the growing season.

215. (D) Permanent stomatal closure is a successful strategy for yield WUE.
Genetic improvement of WUE involves various strategies like selecting for favorable carbon isotope discrimination or developing deeper root systems. While reducing stomatal conductance can improve the ratio of carbon fixed to water lost, permanent stomatal closure is not a viable strategy. Stomata must be open for the plant to acquire carbon dioxide for photosynthesis. Excessive closure would severely limit carbon gain and result in very low yields. The goal is to optimize stomatal regulation rather than eliminate gas exchange entirely.

216. (B) C4 plants discriminate less against heavy carbon.
C4 plants exhibit significantly less carbon isotope discrimination than C3 plants. This is because the CO_2-concentrating mechanism in C4 plants initially uses the enzyme PEP carboxylase, which does not discriminate strongly against $^{\{13\}}C$. Furthermore, the high internal CO_2 concentration generated in the bundle sheath cells forces the Rubisco enzyme to fix almost all of the carbon that is supplied, leaving little opportunity for discrimination. As a result, C4 plant tissues have a higher ratio of $^{\{13\}}C$ to $^{\{12\}}C$ than those of C3 plants.

217. (D) High-performance liquid chromatography of pigments.
Water use efficiency can be evaluated using a variety of methodologies, such as weighing lysimeters for whole-plant water loss, mass spectrometry for carbon isotope ratios, and infrared gas analysis for instantaneous leaf-level exchange. These techniques provide direct or integrated measures of the relationship between carbon gain and water loss. However, high-performance liquid chromatography (HPLC) is a technique used to separate and quantify chemical components like pigments and secondary

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metabolites. It is not a recognized method for assessing or measuring WUE.

218. (A) Breeding for optimal LAI and favorable alleles.
The most effective long-term strategy for enhancing water use efficiency in major crops like wheat is through genetic improvement. This involves breeding for complex traits such as an optimal Leaf Area Index, which balances light interception with water loss, and the selection of favorable alleles that improve stomatal regulation and carbon fixation. This integrated approach addresses the biological and structural factors that determine how a plant manages its water resources, leading to more resilient and productive cultivars in water-limited environments.

219. (D) Excessive nitrogen leading to uncontrolled growth.
Many agricultural practices can improve water use efficiency, such as using drip irrigation to reduce waste, mulching to prevent soil evaporation, and selecting varieties with a high harvest index. However, applying excessive nitrogen fertilizer can actually decrease WUE. It often leads to the production of excessive leaf biomass and an oversized canopy, which increases the total amount of water lost through transpiration. This uncontrolled growth can rapidly deplete soil moisture reserves, leaving the plant vulnerable during later, more critical stages of development.

220. (A) Leakage of electrolytes from leaf tissue discs.
The Membrane Stability Index (MSI) is a physiological marker used to assess a plant's ability to tolerate dehydration or other environmental stresses. It is measured by evaluating the leakage of electrolytes from leaf tissue samples that have been subjected to stress. When cell membranes are damaged by drought, they become more permeable, allowing ions to leak out. A higher MSI value indicates that the membranes have remained intact and stable, reflecting the plant's cellular tolerance and its overall capacity to withstand water deficit.

221. (B) Active transpiration and access to soil moisture.
Canopy Temperature Depression (CTD) is the difference between the temperature of the plant canopy and the ambient air temperature. A cooler canopy, where the CTD is positive, is a strong indicator that the plant is actively transpiring. This suggests that the plant has sufficient access to soil moisture and that its stomata are open. Transpiration provides the necessary evaporative cooling to keep the foliage below the air temperature. In contrast, a warm canopy relative to the air signals stomatal closure and water stress.

222. (B) Active accumulation of compatible osmolyte solutes.
Osmotic adjustment is a key physiological mechanism for drought tolerance that involves the active accumulation of solutes, such as sugars, amino acids, and ions, within the plant cells. By increasing the internal solute concentration, the plant lowers its osmotic and total water potential. This allows the cell to maintain a favorable gradient for water uptake from the soil and to keep its turgor pressure positive even as the soil dries out. This process is found in many mesophytes and is essential for survival during drought.

223. (B) Lower osmotic potential without interfering with enzymes.
Proline is a common amino acid that accumulates in large quantities in many plants during water stress. It functions as a compatible osmolyte, meaning it can be highly concentrated in the cytoplasm to lower the osmotic potential without negatively affecting the structure or function of cellular enzymes. By contributing to osmotic adjustment, proline helps the plant maintain turgor and hydration. It also plays a role in protecting proteins from denaturation and in scavenging reactive oxygen species that are produced during stress.

224. (A) Stabilization of Photosystem II and membrane integrity.
Glycine betaine is a quaternary ammonium compound that acts as a potent osmoprotectant in many drought-tolerant species. Beyond its role in osmotic adjustment, it is essential for protecting the plant's metabolic machinery from the effects of dehydration. Glycine betaine helps stabilize the structure of proteins and complex membrane-bound systems, particularly the Photosystem II complex in the chloroplasts. By maintaining membrane integrity and photosynthetic performance under stress, it significantly contributes to the plant's overall

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resilience to water deficit and other environmental fluctuations.

225. (A) Loss of turgor in specialized epidermal bulliform cells.
Leaf rolling is a classic morphological response to water deficit, especially in many grass species. This movement is driven by specialized, large, thin-walled epidermal cells known as bulliform cells, which are located in the upper epidermis. When the plant experiences water stress, these cells lose turgor pressure and shrink more rapidly than the surrounding cells. This differential loss of turgor causes the leaf to roll or fold inward, reducing the surface area exposed to sunlight and wind and helping to conserve water.

226. (D) Cultivars with higher CTD (cooler canopies) under stress are often more drought-susceptible.
Physiological markers provide valuable insights into drought resistance. A higher Membrane Stability Index (MSI) and increased activity of ROS-scavenging enzymes are both indicators of greater tolerance. Similarly, the retention of high relative water content (RWC) under stress is a positive trait. However, cultivars with a higher Canopy Temperature Depression (CTD)—meaning they have cooler canopies—are generally more drought-resistant or better at avoiding stress, as they can maintain transpiration and water uptake longer than susceptible varieties that close their stomata and overheat.

227. (A) A cooler canopy temperature and higher water content.
When compared under the same water-deficit conditions, a drought-tolerant wheat cultivar typically performs better than a susceptible one by maintaining higher tissue hydration and metabolic activity. This is reflected in a higher relative water content and a cooler canopy temperature, as the tolerant cultivar may have better root access to water or more effective osmotic adjustment. A higher Membrane Stability Index would also be expected. In contrast, the susceptible cultivar would show rapid turgor loss, stomatal closure, and a significant increase in leaf temperature.

228. (D) Lignin
Compatible solutes, or osmoprotectants, are small, highly soluble molecules like proline, trehalose, and glycine betaine that accumulate in the cytoplasm during stress. They function to lower the osmotic potential and protect cellular structures without being toxic to the cell. Lignin, however, is a complex, insoluble structural polymer that is deposited in the cell walls to provide mechanical strength and waterproofing. While lignin is essential for the structure of vascular tissues, it does not participate in osmotic adjustment or act as a soluble osmoprotectant during drought.

229. (D) Accelerated rate of xylem cavitation at tensions.
Several traits are reliable indicators of a plant's ability to withstand drought, including a high root-to-shoot ratio for better water uptake, delayed leaf rolling which suggests turgor maintenance, and substantial osmotic adjustment through proline accumulation. However, an accelerated rate of xylem cavitation at low tensions is a sign of extreme vulnerability to drought. Resistance to cavitation, which allows the plant to maintain a functional water column even under high stress, is a critical trait for drought tolerance and survival in dry environments.

230. (A) Provide a rapid, integrated assessment of stress.
In large-scale plant breeding programs, visual scores for leaf wilting and rolling are highly valuable because they allow for the rapid screening of thousands of genotypes. These scores provide an integrated assessment of the plant's overall water status, reflecting the combined effects of root efficiency, stomatal regulation, and osmotic adjustment. While they do not provide a precise numerical value for water potential, they are highly effective for identifying the most resilient individuals in a population under field conditions where more detailed physiological measurements would be impractical.

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CHAPTER 02

Metabolic Processes and Growth Regulation

2007

1. According to the First Law of Thermodynamics in plant bioenergetics, which of the following statements most accurately describes energy transformation during photosynthesis?

(A) Energy is not created or destroyed, but transformed from radiant energy into chemical bonds during photosynthesis.

(B) The total energy of the chloroplast and its surroundings decreases as light energy is converted into chemical energy.

(C) Entropy within the chloroplast must constantly increase to drive the endergonic synthesis of ATP.

(D) The conversion of light to chemical energy transfers exactly 100% of the energy from absorbed photons into glucose.

2006

2. The Gibbs free energy change (ΔG) determines the spontaneity of a biochemical reaction. Under standard biological conditions, if a reaction has a positive $\Delta G^{\circ\prime}$, how can it proceed in the forward direction in a plant cell?

(A) By decreasing the temperature significantly to lower the enthalpy requirement.

(B) By increasing the concentration of products relative to the reactants.

(C) By coupling it to an exergonic reaction with a larger negative ΔG, like ATP hydrolysis.

(D) By utilizing a specific enzyme that shifts the reaction equilibrium constant exclusively towards the products.

2023

3. Which of the following statements regarding the chemical potential of water in plant systems is INCORRECT?

(A) Addition of solutes to pure water increases its chemical potential above zero.

(B) It is defined as the partial molar free energy of water in a system.

(C) The chemical potential of pure water at standard temperature and pressure is conventionally set to zero.

(D) Water moves spontaneously from a region of higher chemical potential to a region of lower chemical potential.

2023

4. The Nernst equation is fundamental in understanding redox potential in the electron transport chain. Which of the following parameters does NOT directly factor into the Nernst equation for calculating the reduction potential of a half-cell?

(A) The universal gas constant (R).

(B) The absolute temperature (T).

(C) The number of moles of electrons transferred (n).

(D) The activation energy of the electron transfer (E_a).

2012

5. In plant bioenergetics, what is the direct physiological effect of a highly elevated ATP/ADP ratio on the cellular free energy state?

(A) It causes a complete cessation of mitochondrial respiration regardless of metabolic demand.

(B) It reduces the magnitude of the negative ΔG for hydrolysis, slowing down ATP-dependent processes.

(C) It increases the proton motive force across the thylakoid membrane without affecting ATP synthase.

(D) It shifts the equilibrium of adenylate kinase exclusively towards AMP production.

2023

6. When comparing standard chemical state and standard biological state in thermodynamics, what is the primary distinction regarding proton concentration?

(A) The standard chemical state assumes a neutral pH of 7.0 to reflect standard physiological conditions.

(B) The standard chemical state assumes a pH

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of 14, while the biological state assumes pH 7.

(C) The standard chemical state assumes $[H^+]$ is 1 M (pH 0), whereas the biological state assumes $[H^+]$ is $10^{\{-7\}}$ M (pH 7).

(D) The biological state incorporates the buffering capacity of the cytosol, ignoring absolute H^+ concentration.

2016

7. All of the following are primary electron acceptors or donors governed by redox potentials in the photosynthetic electron transport chain, EXCEPT:

(A) Plastoquinone.

(B) Ferredoxin.

(C) Cytochrome b6f.

(D) Fructose-1,6-bisphosphatase.

2009

8. Identify the correct pair associating a thermodynamic variable with its standard SI unit of measurement.

(A) Entropy - Joules per Kelvin per mole.

(B) Enthalpy - Kelvin per mole.

(C) Chemical potential - Watts per square meter.

(D) Redox potential - Coulombs per mole.

2003

9. Which of the following is the most appropriate definition of the electrochemical potential gradient across a plant cellular membrane?

(A) The difference in solute concentration across the bilayer ignoring the specific charge of the ions involved.

(B) The sum of the chemical concentration gradient and the electrical potential difference across the membrane.

(C) The exclusive measurement of proton accumulation in the thylakoid lumen.

(D) The physical pressure exerted by water moving across a semipermeable membrane.

2003

10. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.

Assertion (A): Enzymes are classified into six main classes by the Enzyme Commission (EC) strictly based on the alphabetical order of their trivial names.

Reason (R): The EC classification system assigns a four-digit number to each enzyme representing its class, subclass, sub-subclass, and specific serial number based on the chemical reaction catalyzed.

(A) Both A and R are true and R is the correct explanation of A.

(B) Both A and R are true but R is not the correct explanation of A.

(C) A is true but R is false.

(D) A is false but R is true.

2024

11. The Michaelis-Menten kinetic model fundamentally assumes which of the following conditions during the initial phase of an enzyme-catalyzed reaction?

(A) The rate of enzyme-substrate complex formation equals its rate of breakdown under steady-state conditions.

(B) The concentration of the reaction product is maintained at a significantly higher level than that of the substrate.

(C) The enzyme is constantly being degraded and re-synthesized during the reaction.

(D) The reaction velocity increases exponentially without any saturation point.

2022

12. According to the EC nomenclature, enzymes that catalyze the joining of two molecules with the concomitant hydrolysis of the pyrophosphate bond in ATP belong to which class?

(A) EC 2 (Transferases).

(B) EC 4 (Lyases).

(C) EC 5 (Isomerases).

(D) EC 6 (Ligases).

2015

13. Identify the correct statement regarding the Lineweaver-Burk (double-reciprocal) plot for enzyme kinetics.

(A) The y-intercept represents the value of $-\frac{1}{K_m}$.

(B) The x-intercept represents the value of $\frac{1}{V_{\max}}$.

(C) It provides a direct exponential curve that clearly displays reaction saturation.

(D) The slope of the line is equal to $\frac{K_m}{V_{\max}}$.

2019

14. Identify the INCORRECT pair regarding mechanisms of enzyme inhibition and their kinetic parameters.

(A) Competitive inhibition — Apparent K_m increases, $V_{\{}\max_{\}}$ remains unchanged.

(B) Non-competitive inhibition — Apparent K_m remains unchanged, $V_{\{}\max_{\}}$ decreases.

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(C) Uncompetitive inhibition — Both apparent K_m and $V_{\{}max_{\}}$ increase proportionally.
(D) Mixed inhibition — Both apparent K_m and $V_{\{}max_{\}}$ are altered.

2024

15. Based on the mechanism of uncompetitive inhibition, what inference can be drawn about the binding behavior of the inhibitor?
(A) It binds specifically to the active site, directly competing with the substrate.
(B) It binds exclusively to the enzyme-substrate (ES) complex, not the free enzyme.
(C) It covalently modifies the enzyme, leading to irreversible denaturation.
(D) It binds to the free enzyme and prevents the substrate from accessing the active site.

2010

16. In enzyme kinetics, what does the turnover number ($k_{\{cat\}}$) mathematically represent?
(A) The specific substrate concentration at which the reaction velocity is exactly half-maximal for that enzyme.
(B) The mathematical ratio of the forward and reverse rate constants of the final catalytic step.
(C) The total number of enzyme molecules present in the reaction mixture under standard conditions.
(D) The maximum number of substrate molecules converted to product per active site per unit time at saturation.

2012

17. What is a primary physiological advantage of allosteric regulation over covalent modification in controlling plant enzyme activity?
(A) Allosteric effectors induce rapid, reversible conformational changes to respond to fluctuating cellular metabolite levels.
(B) Allosteric regulation is generally slower and more stable against rapid fluctuations in environmental conditions.
(C) Allosteric regulation permanently alters the enzyme structure, ensuring long-term adaptation.
(D) It requires continuous ATP hydrolysis, coupling enzyme activity directly to energy abundance.

2021

18. Which of the following definitions correctly describes an apoenzyme?
(A) A fully functional enzyme complex consisting of the protein component and a bound organic or inorganic cofactor.
(B) A specific type of coenzyme derived strictly from essential water-soluble vitamins in the diet.
(C) An enzyme that lacks its required organic or inorganic cofactor and is catalytically inactive.
(D) An inactive precursor protein that must undergo specific proteolytic cleavage to become active.

2014

19. Which of the following factors is least relevant to the determination of the K_m of a specific plant enzyme for its substrate under strictly controlled in vitro assay conditions?
(A) The total concentration of the enzyme added to the assay.
(B) The precise amino acid sequence of the enzyme's active site.
(C) The pH of the reaction buffer.
(D) The temperature at which the reaction is incubated.

2008

20. Match the plant transcription factor families in List I with their characteristic DNA-binding motifs or functional roles in List II.
List I: (Transcription Factor Families)
P. WRKY
Q. bZIP
R. MYB
S. NAC
List II: (Characteristics)
1. Basic leucine zipper domain involved in light and stress signaling.
2. Characterized by a highly conserved WRKYGQK heptapeptide sequence.
3. Contains one to three imperfect repeats of a helix-turn-helix motif.
4. Plant-specific factors crucial for development and abiotic stress responses.
(A) P-2, Q-1, R-3, S-4
(B) P-1, Q-2, R-4, S-3
(C) P-3, Q-4, R-1, S-2
(D) P-4, Q-3, R-2, S-1

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2017

21. What is the fundamental mechanism of the 26S proteasome in plant cells?
(A) It degrades intact proteins into free amino acids within the vacuole through acidic hydrolysis.
(B) It degrades polyubiquitinated proteins via

ATP-dependent proteolysis in the cytosol and nucleus.
(C) It synthesizes new polypeptide chains based on mRNA templates attached to the endoplasmic reticulum.
(D) It targets and refolds misfolded or damaged proteins utilizing specialized chaperonins and heat shock factors.

2024

22. In the context of the ubiquitin-proteasome system, what is the role of the E2 enzyme?
(A) It initially activates ubiquitin by forming a thioester bond using ATP.
(B) It acts as the primary recognition element that connects specifically to the target substrate.
(C) It transfers the activated ubiquitin to the target protein directly or to an E3 ligase.
(D) It cleaves ubiquitin chains from proteins prior to their entry into the proteasome core.

2019

23. During ubiquitin-mediated protein degradation, what dictates the high substrate specificity required for targeted proteolysis in plants?
(A) The abundance of the E1 ubiquitin-activating enzyme.
(B) The proteolytic activity of the 20S core particle of the proteasome.
(C) The concentration of free ubiquitin monomers in the cytoplasm.
(D) The structural diversity and substrate recognition domains of various E3 ubiquitin ligases.

2009

24. Identify the INCORRECT statement regarding the mechanisms of translation in plant cells.
(A) Chloroplasts utilize 80S ribosomes identical to those found in the cytosol for synthesizing photosynthetic proteins.
(B) Initiation typically involves the binding of the 40S ribosomal subunit to the 5' cap of the mRNA.
(C) Plant cytosolic ribosomes are structurally designated as 80S, composed of 60S and 40S subunits.
(D) The eukaryotic initiation factor 4F (eIF4F) complex plays a crucial role in mRNA recruitment.

2009

25. What is the direct cause and effect of ATP hydrolysis by the E1 ubiquitin-activating enzyme?
(A) It causes the degradation of the target protein inside the proteasome core.
(B) It facilitates the formation of a high-energy thioester bond between E1 and the C-terminus of ubiquitin.
(C) It drives the physical transport of ubiquitinated proteins across the nuclear envelope.
(D) It triggers the auto-ubiquitination and subsequent destruction of E3 ligases.

2017

26. Which specific pathway relates the in vivo half-life of a protein to the identity of its amino-terminal residue?
(A) The secretory pathway.
(B) The N-end rule pathway.
(C) The unfolded protein response.
(D) The nonsense-mediated decay pathway.

2016

27. All of the following are characteristic core promoter elements recognized by plant RNA polymerase II, EXCEPT:
(A) Shine-Dalgarno sequence.
(B) TATA box.
(C) Initiator (Inr) element.
(D) Y Patch (pyrimidine patch).

2010

28. Which type of polyubiquitin chain linkage is canonically recognized by the 26S proteasome for targeting proteins for degradation?
(A) Lysine-11 (K11) linkage.
(B) Lysine-63 (K63) linkage.
(C) Lysine-48 (K48) linkage.
(D) Methionine-1 (M1) linear linkage.

2025

29. When comparing cytosolic and chloroplastic translation mechanisms in plants, which of the following represents a major distinction?
(A) Cytosolic translation utilizes formylmethionine for initiation, whereas chloroplastic translation uses standard methionine.
(B) Cytosolic ribosomes are sensitive to chloramphenicol, while chloroplastic ribosomes are sensitive to cycloheximide.
(C) Cytosolic translation occurs strictly co-transcriptionally, whereas chloroplastic translation is spatially separated from

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transcription.

(D) Chloroplastic mRNAs often lack a 5' cap and poly-A tail, relying on Shine-Dalgarno-like sequences for ribosome binding.

2009

30. Consider the following statements regarding chloroplast ultrastructure:

I. Grana are stacks of thylakoid membranes enriched in Photosystem II.

II. Stroma lamellae connect granal stacks and are enriched in Photosystem I and ATP synthase.

III. The inner envelope membrane of the chloroplast is highly permeable to most ions and metabolites without transporters.

Which of the above statement(s) is/are correct?

(A) I and II

(B) I and III

(C) II and III

(D) II only

2013

31. Structurally, how does chlorophyll *b* differ from chlorophyll *a*?

(A) Chlorophyll *b* lacks a phytol tail, making it water-soluble.

(B) Chlorophyll *b* has a formyl group (-CHO) instead of a methyl group (-CH3) on the porphyrin ring II.

(C) Chlorophyll *b* contains an iron ion (Fe2+) at the center of the porphyrin ring structure instead of the usual magnesium.

(D) Chlorophyll *b* is missing the entire cyclopentanone ring structure.

2007

32. Identify the correct pair associating a photosynthetic pigment with its primary absorption maxima in the visible light spectrum.

(A) Chlorophyll a — exclusively absorbs in the green region (500-550 nm).

(B) Phycoerythrin — absorbs maximally in the far-red region (700-750 nm).

(C) Chlorophyll b — absorbs maximally in the yellow region (570-590 nm).

(D) Beta-carotene — absorbs strongly in the blue region (400-500 nm).

2018

33. The action spectrum of photosynthesis provides critical physiological information because it demonstrates:

(A) The relative effectiveness of different wavelengths of light in driving the overall photosynthetic process.

(B) The exact chemical structure and molecular weight of all pigments in the leaf.

(C) The speed at which carbon dioxide diffuses into the stomatal cavity.

(D) The absolute quantity of photons absorbed by the chloroplast envelope.

2025

34. Identify the INCORRECT statement regarding the spatial organization of thylakoid membranes.

(A) The appressed regions of grana thylakoids are primarily populated by Photosystem II complexes.

(B) The non-appressed regions (stroma lamellae) predominantly house Photosystem I and ATP synthase.

(C) Cytochrome b6f complexes are exclusively restricted to the stroma lamellae.

(D) The segregation of photosystems prevents energy spillover from PSII to PSI.

2009

35. What is the physiological cause and effect of severe magnesium deficiency on plant photochemistry?

(A) Inability to synthesize the tetrapyrrole ring center, causing chlorosis and impaired light absorption.

(B) An increase in plastoquinone synthesis, leading to enhanced electron transport.

(C) Overactivation of Rubisco, resulting in excessive carbon fixation and starch build-up.

(D) Accelerated synthesis of anthocyanins to replace chlorophyll in light harvesting.

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2025

36. What is the most appropriate description of the function and location of the Light Harvesting Complex II (LHCII)?

(A) It is located in the stroma and acts as an electron carrier to NADP+.

(B) It forms the essential core reaction center of Photosystem I, mediating the primary charge separation.

(C) It resides in the thylakoid lumen, functioning exclusively in photolysis of water.

(D) It is a peripheral antenna system associated with PSII in grana to capture and funnel excitation energy.

2010

37. All of the following are considered accessory pigments functioning within higher plants, EXCEPT:

(A) Chlorophyll b.
(B) Phycocyanin.
(C) Neoxanthin.
(D) Lutein.

2011

38. How is resonance energy transfer (Förster resonance energy transfer, FRET) defined within the context of photosynthetic antenna systems?
(A) The physical movement of an excited electron from one pigment molecule to another.
(B) The emission of light (fluorescence) by a chlorophyll molecule upon returning to the ground state.
(C) The non-radiative transfer of excitation energy from a donor pigment to an acceptor pigment through dipole-dipole interactions.
(D) The conversion of absorbed light energy directly into heat via the xanthophyll cycle.

2021

39. The "red drop" effect, observed by Emerson, led to the inference that:
(A) Chlorophyll completely loses its ability to absorb light above 680 nm.
(B) Red light selectively destroys the oxygen-evolving complex.
(C) Only non-cyclic photophosphorylation occurs in red algae.
(D) Photosynthesis requires the synergistic cooperation of two distinct photosystems driven by different wavelengths of light.

2018

40. Consider the following components of the Z-scheme electron transport chain:
I. Oxygen Evolving Complex (OEC)
II. Plastoquinone pool
III. Cytochrome b6f complex
IV. Ferredoxin
Which of the above are strictly membrane-bound or embedded within the thylakoid lipid bilayer?
(A) I, II and IV
(B) II and III
(C) I, III and IV
(D) I, II, III and IV

2008

41. In the photochemical reaction center of Photosystem II, the special pair of chlorophyll molecules is designated as P680. What does the "680" signify?
(A) The molecular weight of the chlorophyll dimer in Daltons.
(B) The maximum wavelength of light absorption in nanometers for this specific dimer.
(C) The number of amino acid residues in the D1 reaction center protein.
(D) The redox potential of the pair in millivolts.

2006

42. Identify the correct statement regarding the mechanism of the Oxygen Evolving Complex (OEC).
(A) It requires a cluster of four iron atoms and one calcium atom for its catalytic activity.
(B) It catalyzes the oxidation of two water molecules to yield one molecule of O_2, four protons, and four electrons.
(C) It extracts electrons directly from carbon dioxide during the light reactions.
(D) It is located on the stromal side of the thylakoid membrane.

2003

43. Plastoquinone (PQ) acts as a critical mobile carrier in the thylakoid membrane. How many electrons and protons are accepted by one molecule of PQ to become fully reduced plastoquinol (PQH2)?
(A) Two electrons and two protons.
(B) One electron and one proton.
(C) Two electrons and zero protons.
(D) Four electrons and four protons.

2019

44. When comparing cyclic and non-cyclic photophosphorylation, what is a definitive hallmark of cyclic electron transport?
(A) It generates exactly equimolar amounts of ATP and NADPH during the standard non-cyclic photosynthetic pathway.
(B) It relies entirely on the splitting of water by Photosystem II.
(C) It recycles electrons from Ferredoxin to the Cytochrome b6f complex, generating ATP without NADPH or O_2.
(D) It utilizes exclusively the plastocyanin pool to transfer protons into the lumen.

2001

45. Identify the INCORRECT pair regarding the electron carriers of the Z-scheme and their cellular location.
(A) Plastocyanin — Thylakoid lumen.
(B) Ferredoxin — Chloroplast stroma.
(C) Plastoquinone — Thylakoid membrane interior.
(D) Pheophytin — Intermembrane space of the chloroplast envelope.

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2009

46. The herbicide DCMU (Diuron) effectively inhibits photosynthesis. Based on its mechanism of action, where does DCMU interrupt the electron transport chain?

(A) It blocks electron flow from Ferredoxin to NADP+ reductase.

(B) It uncouples the ATP synthase, allowing protons to leak back into the stroma.

(C) It binds to the QB site of the D1 protein in PSII, preventing electron transfer to the plastoquinone pool.

(D) It destroys the manganese cluster of the oxygen-evolving complex.

2022

47. All of the following are integral components or direct electron acceptors associated with Photosystem I, EXCEPT:

(A) Phylloquinone (Vitamin K1).

(B) Tyrosine residue (TyrZ).

(C) Iron-sulfur clusters (Fx, Fa, Fb).

(D) P700 reaction center.

2016

48. What is the physiological cause and effect relationship of the Q-cycle operating within the Cytochrome b6f complex?

(A) It causes electrons to bypass Photosystem I, resulting in a cessation of NADPH synthesis.

(B) It reverses electron flow back to water, generating reactive oxygen species.

(C) It triggers the phosphorylation of LHCII, leading to state transitions.

(D) It allows the transfer of two protons from the stroma to the lumen for every one electron passing through the complex, increasing the proton motive force.

2003

49. Which statement represents the most appropriate description of the structural architecture of Photosystem I?

(A) It contains a reaction center composed of PsaA and PsaB heterodimers, tightly integrated with a large built-in core antenna system.

(B) It functions strictly as a monomer and is entirely dependent on the D1 and D2 proteins for core structure.

(C) It lacks any bound chlorophylls, relying solely on peripheral phycobilisomes for light harvesting.

(D) It is a water-soluble complex situated loosely in the chloroplast stroma.

2013

50. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.

Assertion (A): The Mehler reaction operates as a photoprotective mechanism by acting as an alternative electron sink under high light intensity.

Reason (R): In the Mehler reaction, electrons from Photosystem I are transferred to molecular oxygen, ultimately reducing it to water without carbon fixation.

(A) Both A and R are true and R is the correct explanation of A.

(B) Both A and R are true but R is not the correct explanation of A.

(C) A is true but R is false.

(D) A is false but R is true.

2022

51. What precisely defines the "water-water cycle" in chloroplasts?

(A) The splitting of water at PSII to generate electrons, which eventually reduce O_2 back to water via PSI and ROS scavenging enzymes.

(B) The evaporation of water via transpiration and its immediate replacement from xylem transport.

(C) The cyclic movement of water between the vacuole and the cytoplasm to maintain turgor pressure during light exposure.

(D) The enzymatic hydration of CO_2 by carbonic anhydrase during the Calvin cycle.

2017

52. Identify the INCORRECT statement regarding the xanthophyll cycle in plants.

(A) It involves the reversible interconversion of violaxanthin, antheraxanthin, and zeaxanthin.

(B) The conversion of violaxanthin to zeaxanthin is catalyzed by violaxanthin de-epoxidase.

(C) Zeaxanthin functions to dissipate excess excitation energy as heat.

(D) The cycle operates in the thylakoid lumen and is activated by a high luminal pH (alkaline conditions).

2018

53. Non-photochemical quenching (NPQ) is essential for plant survival. Which factor is the primary biological trigger that activates the major (qE) component of NPQ?

(A) Accumulation of high levels of stromal NADP+.

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(B) Acidification of the thylakoid lumen due to excessive proton pumping.
(C) A sharp decrease in the proton concentration (high pH) within the thylakoid lumen.
(D) The binding of carbon dioxide to Rubisco activase.

2019

54. In the context of ROS detoxification in chloroplasts, what is the specific catalytic function of Superoxide Dismutase (SOD)?
(A) It converts hydrogen peroxide into water and molecular oxygen.
(B) It utilizes ascorbate to reduce singlet oxygen to water.
(C) It catalyzes the disproportionation of superoxide radicals into hydrogen peroxide and molecular oxygen.
(D) It transfers electrons directly from ferredoxin to glutathione.

2009

55. Identify the correct pair matching the reactive oxygen species (ROS) with the primary chloroplast enzyme responsible for its direct detoxification.
(A) Superoxide radical ($O_2^{\cdot -}$) — Catalase (CAT).
(B) Singlet oxygen ($^1O_2$) — Superoxide dismutase (SOD).
(C) Hydroxyl radical ($OH^{\cdot}$) — Glutathione reductase (GR).
(D) Hydrogen peroxide (H_2O_2) — Ascorbate peroxidase (APX).

2001

56. What is a primary cause and effect relationship observed during severe high-light stress (photoinhibition) targeting Photosystem II?
(A) Excessive excitation leads to oxidative damage and targeted degradation of the D1 reaction center protein.
(B) Light stress causes the permanent fusion of grana stacks, halting all electron transport.
(C) High light triggers the irreversible oxidation of all plastoquinone molecules to pheophytin.
(D) The high energy destroys the chloroplast envelope membrane, releasing thylakoids into the cytosol.

2003

57. All of the following are recognized mechanisms or molecules involved in mitigating reactive oxygen species (ROS) damage in plants, EXCEPT:
(A) Tocopherols (Vitamin E).
(B) Photorespiratory synthesis of glycolate.
(C) Ascorbate-glutathione cycle.
(D) Carotenoid quenching of triplet chlorophyll.

2010

58. Based on the dynamics of the xanthophyll cycle, what inference can be made about a plant transferred abruptly from deep shade to full sunlight?
(A) The pool of violaxanthin will rapidly increase to capture more light.
(B) Violaxanthin de-epoxidase will activate, increasing zeaxanthin levels to dissipate heat.
(C) Zeaxanthin epoxidase will immediately convert all zeaxanthin back to violaxanthin.
(D) The plant will bypass the xanthophyll cycle and solely utilize state transitions for protection.

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2017

59. What is the exact subunit composition of the functional Rubisco holoenzyme (Form I) found in the chloroplasts of higher plants?
(A) Eight large subunits and eight small subunits (L_8S_8).
(B) Four large subunits and four small subunits (L_4S_4).
(C) A single massive polypeptide chain encompassing both catalytic and regulatory domains.
(D) Eight small subunits only, as the large subunits are rapidly degraded post-assembly.

2005

60. Match the mechanisms of Rubisco regulation in List I with their corresponding mediators in List II.
List I: (Mechanisms)
P. Carbamylation
Q. Catalytic chaperone
R. Transition-state analog inhibitor
S. Dark inactivation
List II: (Mediators)
1. CA1P (2-carboxyarabinitol-1-phosphate)
2. CO_2 and Mg^{2+} binding to Lysine-201
3. Binding of RuBP to uncarbamylated active sites
4. Rubisco activase
(A) P-2, Q-4, R-1, S-3
(B) P-4, Q-2, R-3, S-1
(C) P-1, Q-3, R-2, S-4
(D) P-2, Q-1, R-4, S-3

2006

61. Identify the correct statement regarding the mechanism of action of Rubisco activase.
(A) It covalently attaches a phosphate group to Rubisco, thereby activating the enzyme.
(B) It functions as a protease that cleaves an inhibitory peptide from the Rubisco large subunit.
(C) It actively synthesizes RuBP to maintain high substrate concentrations for Rubisco.
(D) It utilizes ATP hydrolysis to alter Rubisco conformation, promoting the release of tightly bound sugar phosphates.

2003

62. Which specific modification must occur at the active site of Rubisco for it to become catalytically competent?
(A) Phosphorylation of a serine residue by a chloroplast kinase.
(B) Reduction of a disulfide bridge by the ferredoxin-thioredoxin system.
(C) Formation of a carbamate on an epsilon-amino group of a specific lysine residue, followed by Mg^{2+} binding.
(D) Methylation of the small subunit by S-adenosylmethionine.

2004

63. The specificity factor (τ or Ω) of Rubisco represents the relative preference of the enzyme for CO_2 over O_2. If the temperature of a C3 leaf significantly increases, how is this ratio affected?
(A) The specificity factor increases significantly, favoring carboxylase activity over the oxygenase activity.
(B) The specificity factor decreases, favoring oxygenase activity because CO_2 solubility decreases more than O_2 solubility.
(C) The ratio remains perfectly constant because Rubisco kinetics are temperature-independent.
(D) The enzyme shifts entirely to oxygenase activity, ceasing all CO_2 fixation regardless of concentration.

2007

64. Identify the INCORRECT pair regarding Rubisco and its genetic attributes in higher plants.
(A) Rubisco Large Subunit (rbcL) — Encoded by the chloroplast genome.
(B) Rubisco Small Subunit (RBCS) — Encoded by the nuclear genome.
(C) Chaperonins (e.g., Cpn60) — Required for proper folding of the large subunit.
(D) Rubisco Assembly — Occurs exclusively in the cytosol.

2021

65. What is the cause and effect relationship governing Rubisco's response to elevated atmospheric O_2 concentrations under high illumination?
(A) Increased O_2 competitively inhibits carboxylation, leading to enhanced synthesis of 2-phosphoglycolate.
(B) Elevated O_2 irreversibly denatures Rubisco activase, shutting down the Calvin cycle.
(C) O_2 acts as an allosteric activator of Rubisco, boosting the production of 3-phosphoglycerate.
(D) High O_2 triggers the spontaneous breakdown of RuBP into triose phosphates.

2024

66. In the context of Rubisco regulation, CA1P (2-carboxyarabinitol-1-phosphate) is defined as:
(A) A potent allosteric activator synthesized in the light to maximize Calvin cycle flux.
(B) An intermediate metabolite of the photorespiratory pathway.
(C) A nocturnal transition-state analog that binds tightly to the active site, inhibiting Rubisco activity in the dark.
(D) The structural precursor to the Rubisco small subunit.

2007

67. All of the following factors are required for or promote the in vivo activation of Rubisco in the light, EXCEPT:
(A) Accumulation of CA1P.
(B) An increase in stromal pH.
(C) An influx of Mg^{2+} into the stroma.
(D) Activity of Rubisco activase.

2006

68. When comparing Form I and Form II Rubisco, which characteristic distinguishes Form II (found in some bacteria and dinoflagellates)?
(A) Form II is strictly an oxygenase and cannot fix CO_2.
(B) Form II possesses a much higher specificity for CO_2 over O_2 than Form I.
(C) Form II requires iron instead of magnesium for catalysis.
(D) Form II lacks the small subunits, functioning usually as a dimer of large subunits.

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2001

69. According to the stoichiometry of the Calvin-Benson (C3) cycle, what is the exact ATP and NADPH requirement for the assimilation of a single molecule of CO_2?
(A) 2 ATP and 2 NADPH.
(B) 3 ATP and 2 NADPH.
(C) 3 ATP and 3 NADPH.
(D) 9 ATP and 6 NADPH.

2018

70. Consider the following statements regarding the regulation of Calvin-Benson cycle enzymes by the ferredoxin-thioredoxin system:
I. Electrons from Photosystem I are used to reduce ferredoxin.
II. Ferredoxin-thioredoxin reductase (FTR) transfers electrons to thioredoxin, reducing its disulfide bond.
III. Reduced thioredoxin subsequently oxidizes target enzymes, rendering them inactive in the light.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I and III
(C) II and III
(D) I, II and III

2006

71. Identify the INCORRECT statement regarding the reduction phase of the Calvin-Benson cycle.
(A) 3-phosphoglycerate (3-PGA) is phosphorylated by phosphoglycerate kinase to form 1,3-bisphosphoglycerate.
(B) The phosphorylation of 3-PGA utilizes ATP generated from the light reactions.
(C) 1,3-bisphosphoglycerate is reduced to glyceraldehyde-3-phosphate by NADP-glyceraldehyde-3-phosphate dehydrogenase.
(D) This phase directly releases the first CO_2 molecule of the cycle.

2015

72. Which sequence of carbon sugar intermediates accurately reflects a portion of the regeneration phase of RuBP in the Calvin cycle?
(A) $C_3 + C_3 \rightarrow C_6$; $C_6 + C_3 \rightarrow C_4 + C_5$.
(B) $C_3 + C_4 \rightarrow C_7$; $C_7 + C_3 \rightarrow C_5 + C_5$.
(C) $C_6 + C_3 \rightarrow C_5 + C_4$; $C_4 + C_3 \rightarrow C_7$.
(D) $C_5 + C_5 \rightarrow C_{10} \rightarrow C_3 + C_7$.

2009

73. If a mutation inactivates ferredoxin-thioredoxin reductase (FTR) in a C3 plant, what metabolic consequence is most likely upon exposure to light?
(A) Rubisco will fail to bind CO_2.
(B) Key cycle enzymes like FBPase and SBPase will remain in their oxidized, inactive state, stalling carbon fixation.
(C) The cyclic electron transport chain will run uncontrollably, producing excessive ATP.
(D) The plant will switch to C4 photosynthesis.

2013

74. Identify the correct pair matching a Calvin-Benson cycle enzyme with the specific reaction it catalyzes.
(A) Phosphoribulokinase — Converts ribose-5-phosphate to ribulose-5-phosphate.
(B) Transketolase — Transfers a two-carbon unit from a ketose to an aldose.
(C) Aldolase — Cleaves a six-carbon sugar into three two-carbon fragments.
(D) Epimerase — Converts glyceraldehyde-3-phosphate to dihydroxyacetone phosphate.

2003

75. All of the following enzymes catalyze essentially irreversible reactions that drive the Calvin-Benson cycle forward, EXCEPT:
(A) Phosphopentose isomerase.
(B) Ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco).
(C) Fructose-1,6-bisphosphatase.
(D) Sedoheptulose-1,7-bisphosphatase.

2011

76. What is the cause and effect of the light-induced stromal pH shift on Fructose-1,6-bisphosphatase (FBPase) activity?
(A) The decrease in stromal pH to ~5.0 during the light induces a conformational change that inactivates FBPase.
(B) The pH shift directly cleaves the disulfide bonds of FBPase without the need for thioredoxin.
(C) The increase in stromal pH to ~8.0 provides the optimal alkaline environment for FBPase, promoting its activity.
(D) The alkaline pH denatures FBPase, restricting the cycle to operate only in the dark.

2022

77. In the context of the Calvin-Benson cycle, the aldolase reaction is defined by its ability to:
(A) Transfer a three-carbon ketose fragment to an aldose acceptor.
(B) Hydrolyze the phosphate group from carbon 1 of Fructose-1,6-bisphosphate.

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(C) Isomerize a ketose sugar into an aldose sugar.
(D) Condense two three-carbon sugars (e.g., DHAP and GAP) to form a six-carbon sugar bisphosphate (e.g., FBP).

2010

78. Based on the enzymatic mechanisms of regeneration, what inference can be made regarding carbon flow if a specific inhibitor selectively blocks transketolase activity?
(A) Only the formation of Sedoheptulose-1,7-bisphosphate will be directly halted.
(B) Ribulose-5-phosphate will rapidly accumulate to toxic levels.
(C) The production of both Erythrose-4-phosphate (C4) and Xylulose-5-phosphate (C5) will be immediately severely compromised.
(D) The cycle will compensate by utilizing aldolase to generate C5 sugars directly.

2011

79. The fundamental anatomical feature known as Kranz anatomy in C4 plants is characterized by:
(A) A lack of distinct mesophyll cells, with all photosynthesis occurring in the epidermis.
(B) A concentric arrangement of closely spaced mesophyll cells surrounding enlarged, chloroplast-rich bundle sheath cells.
(C) Bundle sheath cells that completely lack chloroplasts, acting only as structural support for xylem.
(D) Thickened waxy layers exclusively on the lower epidermis to prevent water loss.

2009

80. Consider the following structural and biochemical features of C4 photosynthesis subtypes:
I. NADP-malic enzyme (NADP-ME)
II. NAD-malic enzyme (NAD-ME)
III. Phosphoenolpyruvate carboxykinase (PCK)
IV. C2-oxidative cycle
Which of the above are universally recognized C4 biochemical subtypes?
(A) I and II
(B) I, II and III
(C) II and III
(D) I and III

2012

81. Identify the correct statement regarding the initial step of CO_2 fixation in C4 photosynthesis.
(A) It utilizes PEP carboxylase to fix bicarbonate (HCO_3^-) into oxaloacetate in the cytosol of mesophyll cells.
(B) It occurs in the bundle sheath cells and is catalyzed by Rubisco.
(C) It involves the direct diffusion of gaseous CO_2 into the thylakoid lumen to form malate.
(D) It requires the ATP-dependent carboxylation of pyruvate directly into aspartate.

2015

82. Which of the following is a distinguishing kinetic characteristic of Phosphoenolpyruvate (PEP) carboxylase compared to Rubisco?
(A) PEP carboxylase has a pronounced oxygenase activity.
(B) PEP carboxylase utilizes CO_2 strictly in its unhydrated gaseous form.
(C) PEP carboxylase has a much higher affinity for its substrate (HCO_3^-), allowing efficient function at very low internal CO_2 concentrations.
(D) PEP carboxylase requires activation by Rubisco activase in the light.

2017

83. When comparing the water use efficiency (WUE) of typical C3 and C4 plants under high-temperature, high-light environments, which statement is true?
(A) C4 plants have higher WUE because the efficient PEP carboxylase allows them to maintain high photosynthetic rates with partially closed stomata.
(B) C3 plants have higher WUE because they keep stomata widely open to cool the leaves.
(C) They have identical WUE because both ultimately use Rubisco for carbon assimilation.
(D) C4 plants have lower WUE due to the extra ATP cost of regenerating PEP.

2005

84. Identify the INCORRECT pair associating a C4 subtype with its primary decarboxylating enzyme and location.
(A) NADP-ME subtype — NADP-malic enzyme in the bundle sheath chloroplast.
(B) NAD-ME subtype — NAD-malic enzyme in the bundle sheath mitochondria.
(C) PCK subtype — PEP carboxykinase in the bundle sheath cytosol.
(D) NADP-ME subtype — Pyruvate phosphate dikinase in the bundle sheath vacuole.

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2009

85. All of the following are primary transport metabolites shuttled between mesophyll and bundle sheath cells in the NADP-ME subtype of C4 plants, EXCEPT:
(A) Malate.
(B) Aspartate.
(C) Pyruvate.
(D) Phosphoenolpyruvate (PEP).

2001

86. What is the cause and effect of the presence of suberin lamellae in the bundle sheath cell walls of many C4 plants?
(A) It increases the rapid diffusion of O_2 into the bundle sheath, promoting photorespiration.
(B) It totally blocks the transport of malate from the mesophyll, forcing the use of the aspartate pathway.
(C) It significantly reduces the efflux (leakage) of CO_2 out of the bundle sheath, maintaining high CO_2 concentration around Rubisco.
(D) It allows unhindered water movement to cool the bundle sheath under heat stress.

2011

87. Which of the following best describes the primary ecological and evolutionary advantage of C4 photosynthesis?
(A) It provides a mechanism to fix carbon entirely in the dark, allowing the plant to conserve water in extreme deserts.
(B) It eliminates the need for nitrogen, allowing survival in extremely nutrient-poor soils.
(C) It enables plants to survive prolonged submergence by utilizing anaerobic fermentation.
(D) It suppresses photorespiration by concentrating CO_2 around Rubisco, which is advantageous in hot, arid, and high-light environments.

2016

88. In the context of C4 photosynthesis, the Carbon Concentrating Mechanism (CCM) is functionally defined as:
(A) The spatial separation of initial atmospheric carbon capture and final Rubisco-mediated fixation to elevate CO_2 at the active site of Rubisco.
(B) The physical trapping of carbon dioxide as calcium carbonate crystals in the vacuole.
(C) The synthesis of highly condensed starch granules in the mesophyll purely for carbon storage.
(D) The active transport of gaseous CO_2 through aquaporins into the mitochondria.

2010

89. The hallmark of Crassulacean Acid Metabolism (CAM) is the temporal separation of primary CO_2 fixation and the Calvin cycle. During which phase does the bulk of atmospheric CO_2 assimilation occur?
(A) Exclusively during the midday when light intensity is highest (Phase III).
(B) Exclusively during the dark period (night) when stomata are open (Phase I).
(C) Continuously throughout a 24-hour cycle.
(D) During the brief transition period at dawn (Phase II).

2019

90. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): In CAM plants, Phosphoenolpyruvate carboxylase (PEPC) is highly active during the night and strongly inhibited during the day.
Reason (R): PEPC is phosphorylated by a specific kinase during the night, rendering it active and insensitive to malate inhibition; whereas it is dephosphorylated during the day, making it highly sensitive to malate.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

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2002

91. Identify the INCORRECT statement regarding the four daily phases of gas exchange in a classic CAM plant.
(A) Phase IV (Late Afternoon): Stomata remain strictly closed, completely relying on internal respiratory CO_2 until nightfall.
(B) Phase I (Night): Stomata are open, CO_2 is fixed by PEPC into malate.
(C) Phase II (Early Morning): Stomata remain open for a burst of CO_2 fixation by both PEPC and Rubisco.
(D) Phase III (Midday): Stomata are tightly closed, malate is decarboxylated, and internal CO_2 rises sharply for Rubisco fixation.

2007

92. In CAM plants, massive amounts of malic acid are synthesized at night. Where is this malic acid primarily stored to prevent cytoplasmic acidification?
(A) In the chloroplast stroma.
(B) In the mitochondria.
(C) In the large central vacuole.
(D) In the apoplastic space.

2006

93. Based on the regulation of CAM, what would occur if a mutation constitutively expressed active PEPC kinase during the day?
(A) The plant would shift permanently to C3 photosynthesis.
(B) Malate would be continuously decarboxylated without entering the vacuole.
(C) Stomata would permanently lock in the open position.
(D) PEPC would remain active during the day, creating a futile cycle competing with Rubisco for CO_2.

2011

94. Identify the correct pair matching the CAM phase with its defining physiological state.
(A) Phase I — Stomata closed, rapid starch synthesis.
(B) Phase II — Stomata closed, peak malate decarboxylation.
(C) Phase III — Stomata closed, high internal CO_2 concentration, active Calvin cycle.
(D) Phase IV — Stomata open, maximal PEPC activity.

2013

95. All of the following are physiological or anatomical features commonly associated with obligate CAM plants, EXCEPT:
(A) Very low transpiration ratios (high water use efficiency).
(B) Thin, highly dissected leaves with exceptionally high stomatal densities.
(C) Extensive succulence with large vacuoles.
(D) Thick cuticles and restricted air spaces within the leaf mesophyll.

2012

96. What is the cause and effect of severe water deficit on a facultative CAM plant (e.g., Mesembryanthemum crystallinum)?
(A) It induces a permanent switch from CAM to C4 metabolism.
(B) It causes the complete loss of PEPC expression, shifting the plant to C2 photorespiration.
(C) It forces stomata to open wider during the day to maximize cooling.
(D) It triggers a transition from C3 photosynthesis to CAM metabolism to conserve water while maintaining some carbon gain.

2011

97. When comparing the fundamental mechanisms of C4 and CAM photosynthesis, the most critical difference is:
(A) C4 utilizes spatial separation (mesophyll vs bundle sheath) for decarboxylation, whereas CAM utilizes temporal separation (day vs night) within the same cell.
(B) C4 uses PEP carboxylase, whereas CAM relies exclusively on Rubisco for initial fixation.
(C) C4 produces malate as an intermediate, whereas CAM produces only aspartate.
(D) C4 plants must close their stomata during the day, while CAM plants keep them open.

2002

98. Mesophyll conductance (g_m) refers to the ease of CO_2 diffusion from the substomatal cavity to the site of carboxylation. Which of the following represents a significant physical barrier contributing to g_m?
(A) The epicuticular wax layer on the leaf surface.
(B) The boundary layer of unstirred air outside the leaf.
(C) The chloroplast envelope membranes and chloroplast stroma.
(D) The size of the stomatal pore aperture.

2014

99. In plant physiology, carbon isotope discrimination ($\Delta^{13}C$) is conceptually defined as:
(A) The phenomenon where plants preferentially utilize the lighter ${}^{\{12\}}CO_2$ isotope over the heavier ${}^{\{13\}}CO_2$ during diffusion and enzymatic fixation.
(B) The absolute ratio of ${}^{\{14\}}C$ to ${}^{\{12\}}C$ in the atmosphere.
(C) The active pumping of ${}^{\{13\}}CO_2$ out of the leaf by ABC transporters.
(D) The rate at which the heavier isotope ${}^{\{13\}}C$ causes spontaneous mutations in chloroplast DNA.

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2014

100. Match the photosynthetic pathways in List I with their typical carbon isotope discrimination ($\delta^{13}C$) values in List II.
List I: (Photosynthetic Pathways)
P. C3 plants
Q. C4 plants
R. Obligate CAM plants
S. Aquatic plants utilizing bicarbonate
List II: (Typical $\delta^{13}C$ values)
1. Approximately -10 to -14‰
2. Approximately -25 to -29‰
3. Approximately -11 to -13‰
4. Highly variable, often between -10 to -20‰
(A) P-2, Q-1, R-3, S-4
(B) P-1, Q-2, R-4, S-3
(C) P-3, Q-4, R-1, S-2
(D) P-2, Q-3, R-4, S-1

2015

101. Identify the correct statement detailing the mechanism of stomatal guard cell opening.
(A) Stomatal opening is driven by a massive efflux of potassium ions (K^+) out of the guard cells.
(B) Plasma membrane H^+-ATPase activation hyperpolarizes the cell, driving K^+ and anion uptake to increase turgor.
(C) Guard cells actively synthesize massive amounts of starch from malate to significantly increase the internal osmotic potential.
(D) Water exits the guard cells through aquaporins, causing them to bow outward.

2016

102. Which specific photoreceptor class mediates the highly sensitive blue light response triggering stomatal opening at dawn?
(A) Phytochromes.
(B) Cryptochromes.
(C) Phototropins.
(D) UVR8 receptors.

2010

103. Identify the INCORRECT pair regarding the series of resistances in the CO_2 diffusion pathway into a leaf.
(A) Boundary layer resistance — Dependent on wind speed and leaf morphology.
(B) Stomatal resistance — Regulated by guard cell turgor and aperture size.
(C) Liquid phase (mesophyll) resistance — Involves dissolution of CO_2 into cell wall water and transport across membranes.
(D) Intercellular airspace resistance — Extremely high resistance due to tight cell packing in spongy mesophyll.

2025

104. Under drought stress, Abscisic Acid (ABA) acts rapidly to induce stomatal closure. Which downstream signaling event is centrally involved in this ABA-mediated closure?
(A) Elevation of cytosolic free calcium ($Ca^{\{2+\}}$), which activates anion efflux channels and inhibits inward K^+ channels.
(B) Persistent activation of the H^+-ATPase pump to maintain hyperpolarization.
(C) Massive accumulation of sucrose in the guard cell vacuole.
(D) Breakdown of the guard cell cytoskeleton leading to cellular collapse.

2003

105. All of the following anatomical or physiological factors generally serve to increase mesophyll conductance (g_m) for CO_2, EXCEPT:
(A) A larger surface area of chloroplasts appressed against the cell membrane facing intercellular spaces.
(B) Increased thickening and suberization of mesophyll cell walls.
(C) Thinner mesophyll cell walls.
(D) High expression of specific aquaporins (e.g., PIPs) facilitating CO_2 transport.

2003

106. What is the direct cause and effect of Rubisco's inherent kinetic discrimination against $^{\{13\}}CO_2$?
(A) It causes C4 plants to have more negative $\delta^{13}C$ values than C3 plants.
(B) It results in plant biomass being depleted in $^{\{13\}}C$ relative to atmospheric CO_2.
(C) It forces the plant to increase stomatal conductance to actively fetch $^{\{13\}}CO_2$.
(D) It triggers photorespiration by increasing the affinity for O_2.

2006

107. By analyzing the $\delta^{13}C$ signature of a C3 crop plant's dry matter, an agronomist notes a significantly less negative value (e.g., -24‰ compared to a well-watered -28‰). What physiological inference can be logically drawn?
(A) The crop likely suffered water stress, causing partial stomatal closure and forcing Rubisco to fix a higher proportion of the heavier $^{\{13\}}CO_2$ inside the leaf.
(B) The crop experienced prolonged periods of high stomatal conductance and high water

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availability.
(C) The crop completely switched its mechanism to C4 photosynthesis midway through the season.
(D) The crop experienced severe nitrogen deficiency without any water stress.

2018

108. The photorespiratory pathway (C2 oxidative photosynthetic carbon cycle) relies on the coordinated action of three distinct cellular organelles. What are they?
(A) Chloroplast, Mitochondrion, and the Nucleus.
(B) Peroxisome, Mitochondrion, and Endoplasmic Reticulum.
(C) Chloroplast, Peroxisome, and Mitochondrion.
(D) Chloroplast, Vacuole, and the Golgi apparatus.

2002

109. Identify the INCORRECT statement regarding the specific metabolic steps of the photorespiratory pathway.
(A) Phosphoglycolate phosphatase converts 2-phosphoglycolate to glycolate in the chloroplast.
(B) Glycolate is oxidized to glyoxylate in the peroxisome, producing hydrogen peroxide.
(C) Serine hydroxymethyltransferase catalyzes the conversion of glycine to serine in the mitochondrion.
(D) Glyoxylate is transported directly to the mitochondrion, where it is decarboxylated.

2010

110. Consider the following statements regarding the release and reassimilation of ammonia during photorespiration:
I. Ammonia is released in the mitochondria during the conversion of two molecules of glycine into one molecule of serine.
II. If this ammonia is not rapidly reassimilated, the plant will lose critical nitrogen and suffer severe toxicity.
III. The reassimilation of this ammonia is strictly handled by the mitochondria.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I and III
(C) II and III
(D) I only

2007

111. During the final recovery stages of the C2 cycle in the peroxisome, what is serine converted into before its return to the chloroplast?
(A) Glyoxylate, which is then reduced to glycolate.
(B) Hydroxypyruvate, which is then reduced to glycerate.
(C) Pyruvate, which is then phosphorylated to PEP.
(D) Aspartate, which is then converted to malate.

2023

112. Identify the correct pair mapping a photorespiratory enzyme strictly to its resident organelle.
(A) Glycolate oxidase — Chloroplast.
(B) Glutamate:glyoxylate aminotransferase — Chloroplast.
(C) Glycerate kinase — Peroxisome.
(D) Glycine decarboxylase complex (GDC) — Mitochondrion.

2017

113. All of the following metabolites enter the peroxisome from either the chloroplast or mitochondrion during active photorespiration, EXCEPT:
(A) 2-Phosphoglycolate.
(B) Glycolate.
(C) Serine.
(D) Glutamate.

2018

114. Conceptually, why is photorespiration considered highly energetically costly to the plant?
(A) It permanently prevents the formation of any 3-PGA, entirely stopping carbon flow.
(B) It synthesizes massive amounts of starch in the peroxisome, effectively trapping energy that cannot be utilized.
(C) It consumes ATP and reducing equivalents to salvage carbon while releasing previously fixed CO_2.
(D) It requires continuous de novo synthesis of Rubisco.

2011

115. What is the intended cause and effect of engineering synthetic photorespiratory bypasses (e.g., introducing bacterial glycolate catabolic pathways directly into the chloroplast)?
(A) To bypass the mitochondrion, thereby concentrating CO_2 directly within the chloroplast, reducing energy waste and

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increasing photosynthetic yield.
(B) To completely eliminate Rubisco's oxygenase activity by mutating its active site.
(C) To force the plant to excrete glycolate out of the roots as an allelopathic chemical.
(D) To shift the entire Calvin cycle into the peroxisome.

2007

116. When comparing 2-phosphoglycolate and 3-phosphoglycerate (3-PGA) produced at the Rubisco active site, what is a critical difference?
(A) 3-PGA contains two carbon atoms, whereas 2-phosphoglycolate contains three.
(B) 2-phosphoglycolate acts as a potent activator of FBPase, whereas 3-PGA inhibits it.
(C) 3-PGA is strictly exported to the cytosol, whereas 2-phosphoglycolate is permanently stored in the stroma.
(D) 3-PGA can immediately enter the Calvin cycle for reduction, whereas 2-phosphoglycolate must be salvaged via a complex multi-organelle pathway.

2010

117. Beyond carbon salvage, what is the most appropriate description of a beneficial physiological role of photorespiration in C3 plants?
(A) It generates the primary energy (ATP) needed for root growth in the dark.
(B) It protects the photosynthetic apparatus from photooxidative damage under high-light and low CO_2 conditions by maintaining electron flow.
(C) It synthesizes the protective epicuticular wax layer on leaves.
(D) It allows the plant to directly fix atmospheric nitrogen via the GDC complex.

2011

118. Which enzyme catalyzes the first committed and highly regulated step of starch biosynthesis within the chloroplast?
(A) Sucrose-phosphate synthase (SPS).
(B) Starch branching enzyme (SBE).
(C) ADP-glucose pyrophosphorylase (AGPase).
(D) UDP-glucose pyrophosphorylase (UGPase).

2021

119. Identify the correct statement regarding the allosteric regulation of Sucrose-6-phosphate synthase (SPS) in the cytosol.
(A) SPS is strongly activated by inorganic phosphate (Pi) and inhibited by Glucose-6-phosphate.
(B) SPS requires direct binding of thioredoxin for its activation.
(C) SPS activity is entirely independent of light/dark transitions and metabolite levels.
(D) SPS is allosterically activated by Glucose-6-phosphate and inhibited by inorganic phosphate (Pi).

2019

120. Consider the following enzymes involved in nocturnal starch degradation in leaves:
I. Alpha-amylase (AMY)
II. Beta-amylase (BAM)
III. Isoamylase (ISA)
IV. Disproportionating enzyme (D-enzyme)
Which of the above enzymes primarily function to release maltose directly from starch polymers and debranch the glucan chains, respectively?
(A) I and III
(B) II and III
(C) I and IV
(D) II and IV

2006

121. What is the fundamental role of Fructose-2,6-bisphosphate (F-2,6-BP) in plant carbohydrate metabolism?
(A) It is the direct precursor for cellulose biosynthesis in the cell wall.
(B) It acts as a potent regulatory signal molecule in the cytosol, inhibiting cytosolic FBPase and activating PPi-PFK, thereby shifting flux toward glycolysis rather than sucrose synthesis.
(C) It serves as the primary transport sugar in the phloem of cucurbits.
(D) It is a structural component of the starch granule matrix.

2018

122. Identify the INCORRECT pair regarding carbohydrate metabolic enzymes and their strict subcellular localization in a typical leaf mesophyll cell.
(A) Starch synthase — Chloroplast stroma.
(B) ADP-glucose pyrophosphorylase (AGPase) — Vacuole.
(C) Sucrose synthase (SuSy) — Cytosol.
(D) Triose phosphate isomerase — Present in both cytosol and chloroplast.

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2011

123. All of the following are characteristics of the diurnal regulation of transitory starch in plant leaves, EXCEPT:

(A) Starch synthesis continues at its maximal rate throughout the dark period.

(B) Starch accumulates linearly during the photoperiod.

(C) Starch is degraded at a nearly constant rate during the night to support respiration and export.

(D) The rate of starch degradation is adjusted to ensure stores are nearly, but not completely, exhausted by dawn.

2001

124. What is the direct cause and effect if the Triose Phosphate Translocator (TPT) in the inner chloroplast envelope is completely blocked by a specific inhibitor?

(A) Sucrose synthesis in the cytosol will dramatically increase by utilizing fatty acids derived from the chloroplast.

(B) Inorganic phosphate will rapidly accumulate in the stroma, completely inhibiting AGPase.

(C) Triose phosphates accumulate in the stroma, leading to starch overproduction while cytosolic sucrose synthesis is starved.

(D) The plant will immediately shift to exporting malate instead of triose phosphates to synthesize sucrose.

2024

125. The term "transitory starch" is structurally and functionally defined as:

(A) Highly crystalline amylose stored in root amyloplasts for long-term overwintering.

(B) Water-soluble fructans temporarily stored in the vacuole.

(C) Starch synthesized exclusively in the bundle sheath cells of C3 plants.

(D) Granular starch synthesized in the chloroplast during the day and degraded the following night to sustain metabolism.

2002

126. When comparing the biosynthesis of many starch components, which distinction is correct?

(A) Amylose is a highly branched polymer synthesized by branching enzymes, while amylopectin is strictly linear.

(B) Amylose relies on UDP-glucose as a substrate, whereas amylopectin uses ADP-glucose.

(C) Amylose is synthesized primarily by Granule-Bound Starch Synthase (GBSS), whereas amylopectin relies on Soluble Starch Synthases (SS) and Branching Enzymes (SBE).

(D) Amylopectin lacks any $\alpha(1 \rightarrow 6)$ glycosidic linkages.

2014

127. The Münch pressure-flow hypothesis fundamentally states that phloem transport is driven by:

(A) Active pumping of water by aquaporins directly inside the sieve elements.

(B) A mass flow of sap driven by an osmotically generated positive hydrostatic pressure gradient between source and sink regions.

(C) Cytoplasmic streaming (cyclosis) coordinated along the entire length of the sieve tube.

(D) Capillary action and transpirational pull from the leaf surface.

NODIA

2022

128. Identify the INCORRECT statement regarding the polymer trapping model of phloem loading.

(A) Sucrose diffuses through plasmodesmata into specialized intermediary (companion) cells.

(B) In the intermediary cells, sucrose is converted into larger oligosaccharides like raffinose and stachyose.

(C) The larger oligosaccharides are too bulky to diffuse back into the mesophyll, thus concentrating them in the phloem.

(D) It relies entirely on secondary active transporters (H^+/symporters) in the plasma membrane of the sieve element.

2015

129. When contrasting apoplastic and symplastic phloem loading, apoplastic loaders typically exhibit which distinguishing feature?

(A) The reliance on plasma membrane-localized sucrose-proton symporters (e.g., SUT1/SUC2) to actively load sucrose from the cell wall space.

(B) Abundant and highly branched plasmodesmata connecting mesophyll cells directly to the sieve elements.

(C) The exclusive transport of sugar alcohols like mannitol instead of sucrose.

(D) A complete lack of companion cells.

2013

130. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.

Assertion (A): Treating the source leaves of an apoplastically loading plant with a protonophore (which dissipates the proton gradient) halts phloem loading.

Reason (R): Phloem loading in these plants requires a proton motive force generated by the plasma membrane H^+-ATPase to drive sucrose uptake via sucrose/H^+ symporters.

(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2012

131. Identify the correct pair associating a specific type of transported carbohydrate with its corresponding phloem loading mechanism.

(A) Raffinose and Stachyose — Polymer trapping (symplastic loading).
(B) Sucrose exclusively — Polymer trapping (symplastic loading).
(C) Fructose and Glucose — Apoplastic loading via SUT transporters.
(D) Amylopectin — Active vesicular exocytosis into the sieve element.

2009

132. Phloem sap is a highly specialized fluid. All of the following are typical, naturally occurring constituents of phloem sap in healthy plants, EXCEPT:

(A) High concentrations of potassium ions (K^+).
(B) Amino acids and amides (e.g., glutamine, asparagine).
(C) Signaling molecules including mRNA, small RNAs, and phytohormones.
(D) Complex, undigested polysaccharides like cellulose and pectin.

2007

133. The aphid stylet technique is a classic method used in plant physiology. How does this technique elegantly resolve the challenges of sampling phloem sap?

(A) The aphid injects enzymes that convert starch to sucrose, making it measurable.
(B) The aphid stylet precisely penetrates a single sieve tube element without triggering the massive callose and P-protein sealing response, providing pure exudate.
(C) The stylet acts as a microelectrode to measure the exact voltage of the companion cell.
(D) The aphid selectively consumes only apoplastic fluid, avoiding the symplast completely.

2006

134. What is the cause and effect of utilizing an apoplastic phloem unloading mechanism in developing seeds?

(A) It causes immediate water loss from the seed, triggering precocious germination.
(B) It forces the seed to undergo CAM photosynthesis to fix its own carbon.
(C) It ensures that there is no direct symplastic continuity between maternal tissues and the developing embryo, allowing independent genetic and osmotic regulation.
(D) It prevents any carbohydrates from entering the endosperm.

2004

135. In angiosperms, P-proteins and callose are defined structurally and functionally as:

(A) Structural proteins that form the secondary cell wall of sieve elements.
(B) Transport proteins that actively pump sucrose into the vacuole.
(C) Enzymes required for the synthesis of raffinose-family oligosaccharides.
(D) Damage-response mechanisms that rapidly form plugs at sieve plates to prevent the catastrophic loss of high-pressure phloem sap upon injury.

2006

136. When comparing specialized companion cells, how do "intermediary cells" differ primarily from "transfer cells"?

(A) Intermediary cells possess numerous plasmodesmata connections for symplastic loading, whereas transfer cells have cell wall ingrowths adapted for high-capacity apoplastic loading.
(B) Intermediary cells have highly invaginated cell walls to increase surface area, whereas transfer cells lack invaginations entirely.
(C) Intermediary cells are dead at maturity, whereas transfer cells retain their nucleus.
(D) Intermediary cells only transport amino acids, whereas transfer cells exclusively transport sugars.

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2016

137. In the context of whole-plant partitioning, which of the following best defines a "sink" tissue?
(A) Any organ that is actively performing high rates of photosynthesis.
(B) Any organ that relies on the import of photoassimilates to support its growth or storage needs.
(C) Any organ that demonstrates a net export of photoassimilates.
(D) Only the mature, fully expanded leaves at the base of the plant.

2024

138. Identify the correct statement regarding assimilate partitioning during the reproductive phase of an annual crop plant.
(A) Partitioning completely ceases, and all organs become self-sufficient.
(B) Developing seeds/fruits become the dominant sinks, often drawing assimilates heavily from nearby source leaves and sometimes mobilizing reserves from stems.
(C) The roots become the dominant, overriding sink, receiving 90% of assimilates.
(D) Assimilates are exclusively secreted out of the plant into the soil to attract beneficial microbes.

2004

139. Sink strength is a critical concept in determining the competitive ability of an organ to attract assimilates. It is mathematically conceptualized as:
(A) Sink size multiplied by sink activity (the specific rate of uptake and utilization of assimilates).
(B) Sink size divided by the distance from the source leaf.
(C) The total number of chloroplasts within the sink tissue.
(D) The inverse of the turgor pressure within the sink cells.

2019

140. Match the key enzymes operating in sink tissues (List I) with their primary functional roles (List II).
List I: (Enzymes)
P. Cell wall invertase
Q. Vacuolar invertase
R. Sucrose synthase (SuSy)
S. ADP-glucose pyrophosphorylase
List II: (Functional Roles)
1. Cleaves incoming sucrose in the apoplast to maintain a concentration gradient for unloading.
2. Cleaves sucrose into UDP-glucose and fructose, often linked to starch or cellulose biosynthesis.
3. Controls the first committed step of starch synthesis in amyloplasts.
4. Hydrolyzes sucrose internally to regulate osmotic potential and cell expansion.
(A) P-1, Q-4, R-2, S-3
(B) P-2, Q-3, R-1, S-4
(C) P-4, Q-1, R-3, S-2
(D) P-3, Q-2, R-4, S-1

2004

141. Identify the INCORRECT statement regarding the transition of a leaf from sink to source.
(A) Young expanding leaf — Net importer of assimilates (Sink).
(B) Fully expanded mature leaf — Net exporter of assimilates (Source).
(C) Transition phase — Loading and unloading can occur simultaneously in different zones of the same leaf.
(D) Senescing leaf — Reverts back to being a strong sink to import nutrients before death.

NODIA

2011

142. All of the following are physiological or genetic factors that can be manipulated to increase the harvest index of a grain crop, EXCEPT:
(A) Enhancing the efficiency of phloem loading in source leaves.
(B) Increasing the duration of the grain-filling period.
(C) Drastically increasing the height and biomass of the vegetative stem (lodging susceptible).
(D) Upregulating invertase and sucrose synthase activity in the developing grain.

2022

143. During apoplastic phloem unloading into developing legume seeds, how is the steep concentration gradient driving efflux from the maternal seed coat maintained?
(A) By immediately converting all sucrose into callose in the apoplast.
(B) By the rapid and active uptake of sucrose (or its hexose cleavage products) by specific transporters on the cotyledon (embryo) epidermal cells.
(C) By reversing the polarity of the phloem to pump water outwards.
(D) By completely halting respiration in the embryo.

2023

144. What was the critical cause and effect regarding harvest index during the Green Revolution?
(A) Overexpression of Rubisco genes led to massive leaves that monopolized all assimilates, lowering the harvest index.
(B) Complete elimination of root structures allowed all energy to go to the seeds.
(C) The use of chemical desiccants artificially shrunk the plant prior to harvest.
(D) Introduction of dwarfing genes (e.g., Rht in wheat) reduced stem biomass, thereby dramatically increasing the proportion of assimilates partitioned to the grain (higher harvest index).

2013

145. What is the most appropriate description of the signaling role of hexose sugars (glucose and fructose) during early seed development?
(A) Hexoses generated by cell wall invertase often promote cell division and expansion, delaying differentiation and starch storage until the sink size is established.
(B) High hexose concentrations act as a signal to initiate the final desiccation and dormancy phase of the seed.
(C) Hexoses are toxic signaling molecules that induce programmed cell death in the endosperm.
(D) High hexose strictly turns off all genes related to glycolysis.

2025

146. In the classic plant cytosolic glycolysis pathway, what is the net yield of ATP and NADH per molecule of glucose oxidized to two molecules of pyruvate?
(A) 4 ATP and 2 NADH.
(B) 2 ATP and 4 NADH.
(C) 2 ATP and 2 NADH.
(D) 36 ATP and 0 NADH.

2010

147. Identify the INCORRECT statement concerning plant-specific modifications to the standard glycolytic pathway.
(A) PPi-PFK catalyzes a highly irreversible step, forcing glycolysis strongly forward regardless of energy status.
(B) Plants possess a pyrophosphate-dependent phosphofructokinase (PPi-PFK) that acts in parallel with ATP-dependent PFK.
(C) The use of PPi by PPi-PFK helps conserve ATP during periods of energy stress, such as anoxia.
(D) Plants utilize non-phosphorylating NADP-dependent glyceraldehyde-3-phosphate dehydrogenase in the cytosol as a bypass.

2007

148. During prolonged soil flooding (anoxia), plant roots rely on ethanol fermentation. Which two enzymes sequentially catalyze the conversion of pyruvate to ethanol?
(A) Pyruvate dehydrogenase and Alcohol dehydrogenase.
(B) Lactate dehydrogenase and Pyruvate kinase.
(C) PEP carboxylase and Malate dehydrogenase.
(D) Pyruvate decarboxylase and Alcohol dehydrogenase.

2015

149. Identify the correct pair mapping a key glycolytic enzyme to its primary allosteric regulator in plant cells.
(A) ATP-dependent Phosphofructokinase (PFK) — Strongly activated by high ATP/ADP ratio.
(B) Pyruvate kinase — Inhibited by ATP.
(C) Hexokinase — Activated by Glucose-6-phosphate.
(D) PPi-PFK — Inhibited by Fructose-2,6-bisphosphate.

2002

150. Consider the following enzymes that provide alternative or bypass routes in plant respiratory carbon metabolism:
I. PPi-dependent phosphofructokinase (PPi-PFK)
II. Non-phosphorylating NADP-GAPDH
III. Phosphoenolpyruvate carboxylase (PEPC)
IV. Rubisco
Which of the above enzymes directly provide flexibility in cytosolic glycolysis and organic acid formation prior to mitochondrial entry?
(A) I, II and III
(B) I, II, III and IV
(C) II, III and IV
(D) I and II

2022

151. All of the following are generally considered major irreversible, regulatory steps dictating the forward flux of standard glycolysis, EXCEPT:
(A) The phosphorylation of glucose by hexokinase.
(B) The conversion of fructose-6-phosphate to fructose-1,6-bisphosphate by ATP-PFK.

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(C) The conversion of phosphoenolpyruvate to pyruvate by pyruvate kinase.
(D) The interconversion of dihydroxyacetone phosphate and glyceraldehyde-3-phosphate by triose phosphate isomerase.

2012

152. The "Pasteur effect" is classically observed in plant tissues subjected to hypoxia. How does this physiological phenomenon manifest?
(A) Acceleration of glycolytic flux to compensate for the lower ATP yield of fermentation compared to oxidative phosphorylation.
(B) A dramatic decrease in glucose consumption and cessation of glycolysis.
(C) The rapid and complete conversion of all stored starch directly into specialized lipid droplets for energy storage.
(D) The immediate onset of photorespiration to generate oxygen internally.

2016

153. What is the cause and effect sequence regulating the switch between lactic acid and ethanol fermentation during sudden anoxia in plant roots?
(A) Ethanol is produced first until it reaches toxic levels, which then allosterically activates lactate dehydrogenase.
(B) Initial anoxia triggers lactate fermentation, causing cytosolic pH to drop; this acidification inhibits lactate dehydrogenase and activates pyruvate decarboxylase, shifting flux to ethanol production.
(C) Anoxia opens calcium channels that directly destroy pyruvate decarboxylase, forcing only lactate production.
(D) Lack of oxygen causes roots to secrete pyruvate directly into the soil without fermentation.

2014

154. In the context of glycolysis, the term "substrate-level phosphorylation" is precisely defined as:
(A) The synthesis of ATP driven by the flow of protons through the FoF1 ATP synthase.
(B) The direct transfer of a high-energy phosphate group from a metabolic intermediate (e.g., 1,3-bisphosphoglycerate) to ADP to form ATP.
(C) The use of light energy to add a phosphate group to ADP.
(D) The phosphorylation of a protein substrate by a specific kinase to alter its activity.

NODIA

2023

155. When comparing cytosolic and plastidic glycolysis in plant tissues, which functional distinction is accurate?
(A) Isozymes for glycolytic steps exist in both compartments, but plastidic glycolysis primarily provides carbon skeletons (e.g., for lipid synthesis) rather than serving as the main energy-yielding pathway for the whole cell.
(B) Plastidic glycolysis strictly requires PPi, whereas cytosolic glycolysis strictly requires ATP.
(C) Plastidic glycolysis operates entirely independently of the cytosol because the inner envelope is completely impermeable to all glycolytic intermediates.
(D) Plastidic glycolysis only occurs in roots, never in leaves.

2005

156. The ultrastructure of a typical plant mitochondrion includes invaginations of the inner membrane. What are these structures called, and what is their primary function?
(A) Grana; to maximize light capture.
(B) Matrix granulations; to store large amounts of calcium.
(C) Cristae; to drastically increase the surface area available for housing electron transport chain complexes and ATP synthase.
(D) Tonoplasts; to regulate the osmotic potential of the organelle.

2001

157. Identify the correct statement regarding the presence of NAD-malic enzyme in plant mitochondria.
(A) It catalyzes the complete reversal of the TCA cycle to fix CO_2 in the dark.
(B) It strictly requires ATP hydrolysis to function.
(C) It is an integral membrane protein of the outer mitochondrial envelope.
(D) It allows plant mitochondria to oxidize malate directly to pyruvate and CO_2, bypassing the requirement for cytosolic pyruvate entry.

2022

158. In the complete oxidation of one molecule of pyruvate through a single turn of the Tricarboxylic Acid (TCA) cycle, what is the exact yield of reducing equivalents and nucleoside triphosphates?
(A) 2 NADH, 0 FADH2, and 2 ATP.

(B) 3 NADH, 1 FADH2, and 1 ATP (or GTP).
(C) 4 NADH, 1 FADH2, and 1 ATP (or GTP).
(D) 6 NADH, 2 FADH2, and 2 ATP (or GTP).

2007

159. Identify the INCORRECT pair regarding TCA cycle enzymes and the specific type of chemical reaction they catalyze.
(A) Citrate synthase — Condensation reaction.
(B) Succinate dehydrogenase — Substrate-level phosphorylation.
(C) Isocitrate dehydrogenase — Oxidative decarboxylation.
(D) Fumarase — Hydration reaction.

2012

160. Select the correct sequential order of intermediate metabolites produced during the first half of the TCA cycle, starting after the input of Acetyl-CoA.
(A) Citrate → Isocitrate → α-Ketoglutarate → Succinyl-CoA.
(B) Citrate → α-Ketoglutarate → Isocitrate → Succinyl-CoA.
(C) Isocitrate → Citrate → Succinyl-CoA → α -Ketoglutarate.
(D) Succinyl-CoA → α-Ketoglutarate → Isocitrate → Citrate.

2025

161. All of the following enzymes typically participate in anaplerotic (replenishing) reactions that maintain the pool of TCA cycle intermediates in plant cells, EXCEPT:
(A) Cytochrome c oxidase.
(B) Phosphoenolpyruvate (PEP) carboxylase.
(C) Malate dehydrogenase.
(D) Isocitrate lyase (in glyoxysomes).

2006

162. How does the GABA (gamma-aminobutyric acid) shunt function as a bypass in plant mitochondrial metabolism?
(A) It circumvents the entire mitochondrial electron transport chain by utilizing alternative oxidase.
(B) It directly links glycolysis to lipid synthesis by bypassing pyruvate dehydrogenase.
(C) It bypasses the α-ketoglutarate dehydrogenase step of the TCA cycle, converting glutamate to GABA, which is subsequently converted to succinate.
(D) It allows the direct export of ATP from the matrix without the adenine nucleotide translocator.

NODIA

2003

163. The TCA cycle in plants is amphibolic. What is the cause and effect of massive withdrawal of α-ketoglutarate from the cycle during active nitrogen assimilation?
(A) It leads to the synthesis of glutamic acid, while necessitating heightened anaplerotic carbon flow (via PEPC) to replenish cycle intermediates.
(B) It causes the complete and immediate arrest of mitochondrial respiration due to substrate depletion.
(C) It shifts the mitochondria entirely to anaerobic fermentation.
(D) It irreversibly inhibits the action of citrate synthase.

2025

164. The Pyruvate Dehydrogenase Complex (PDC) acts as the critical bridge between glycolysis and the TCA cycle. Functionally, it is defined as a multi-enzyme complex that:
(A) Phosphorylates pyruvate to form PEP.
(B) Reduces pyruvate to lactate to regenerate NAD+.
(C) Condenses two molecules of pyruvate to form citrate.
(D) Catalyzes the oxidative decarboxylation of pyruvate to acetyl-CoA, simultaneously reducing NAD+ to NADH.

2012

165. Determine the correct ordered arrangement of the enzymes catalyzing the latter half of the TCA cycle, from succinyl-CoA to oxaloacetate regeneration, and select the matching option.
(A) Succinyl-CoA synthetase → Succinate dehydrogenase → Fumarase → Malate dehydrogenase.
(B) Succinate dehydrogenase → Fumarase → Succinyl-CoA synthetase → Malate dehydrogenase.
(C) Malate dehydrogenase → Fumarase → Succinate dehydrogenase → Succinyl-CoA synthetase.
(D) Fumarase → Succinyl-CoA synthetase → Malate dehydrogenase → Succinate dehydrogenase.

2022

166. In the mitochondrial electron transport chain (mETC), what is the specific role of Complex II (Succinate dehydrogenase)?
(A) It pumps four protons across the inner membrane while oxidizing NADH.

(B) It directly reduces molecular oxygen to water.
(C) It transfers electrons from succinate to ubiquinone without pumping any protons across the inner membrane.
(D) It catalyzes the synthesis of ATP driven by the proton gradient.

2007

167. Identify the INCORRECT statement regarding the unique features of the plant mitochondrial electron transport chain compared to animal mitochondria.
(A) Plant mitochondria possess alternative NAD(P)H dehydrogenases on both the internal and external faces of the inner membrane.
(B) These alternative NAD(P)H dehydrogenases are completely resistant to the inhibitor rotenone.
(C) Plant mitochondria can oxidize cytosolic NADH directly without requiring a malate-aspartate shuttle.
(D) The transfer of electrons through these alternative dehydrogenases is highly coupled to proton pumping, generating maximum ATP.

2017

168. According to modern estimates based on the stoichiometry of the plant F1Fo-ATP synthase and proton pumping, what is the approximate operational P/O ratio for the oxidation of one molecule of endogenous matrix NADH?
(A) Approximately 2.5.
(B) Approximately 3.0.
(C) Exactly 1.5.
(D) Less than 1.0.

2016

169. Identify the correct pair associating an electron transport chain inhibitor with its exact site of action.
(A) Rotenone — Inhibits Complex I (NADH dehydrogenase).
(B) Cyanide (CN-) — Strongly binds to and inhibits the binuclear center of Complex IV.
(C) Antimycin A — Inhibits Complex III (Cytochrome bc1 complex).
(D) Oligomycin — Directly blocks the F1Fo-ATP synthase.

2019

170. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): The F1Fo-ATP synthase complex acts as a rotary motor to synthesize ATP in the mitochondria.
Reason (R): The flow of protons through the membrane-embedded Fo channel causes a physical rotation of the γ-subunit, which induces conformational changes in the F1 catalytic head, driving the condensation of ADP and Pi.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2004

171. All of the following function as mobile electron carriers shuttling electrons between the large multiprotein complexes of the mitochondrial ETC, EXCEPT:
(A) Plastoquinone.
(B) Ubiquinone (Coenzyme Q).
(C) Cytochrome c.
(D) Cytochrome c1.

2009

172. Plant Uncoupling Proteins (UCPs) mediate a process conceptually similar to the Alternative Oxidase by reducing the efficiency of ATP synthesis. How do they achieve this?
(A) By directly hydrolyzing ATP into ADP and Pi in the matrix.
(B) By stripping electrons directly from ubiquinone and transferring them to water.
(C) By facilitating the re-entry of protons from the intermembrane space back into the matrix, bypassing the ATP synthase and dissipating the gradient as heat.
(D) By blocking the entry of ADP through the adenine nucleotide translocator.

2024

173. The proton motive force (Δp) driving oxidative phosphorylation is composed of two components: the membrane potential ($\Delta\psi$) and the chemical proton gradient (ΔpH). In plant mitochondria, how do these components typically relate?
(A) The ΔpH constitutes over 90% of the driving force, with negligible membrane potential.
(B) The two forces perfectly cancel each other out during normal respiration.

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(C) $\Delta\psi$ is strictly negative on the outside and positive on the inside of the matrix.
(D) The membrane potential ($\Delta\psi$) makes the largest quantitative contribution to the total driving force.

2023

174. In Complex III (Cytochrome bc1 complex), the Q-cycle is fundamentally defined as a mechanism that:
(A) Synthesizes ubiquinone strictly from acetyl-CoA derivatives.
(B) Bypasses the iron-sulfur clusters entirely to prevent ROS formation.
(C) Routes electrons from ubiquinol to cytochrome c while effectively doubling the number of protons pumped across the membrane per electron pair.
(D) Cycles electrons indefinitely within the complex until light is present.

2017

175. When comparing the ATP synthase found in chloroplast thylakoids (CF_1CF_o) with that in plant mitochondria (F_1F_o), which statement highlights a significant difference?
(A) The mitochondrial complex synthesizes ATP in the matrix, whereas the chloroplast complex synthesizes ATP in the thylakoid lumen.
(B) The chloroplast ATP synthase is uniquely regulated by light/dark transitions via a built-in redox-sensitive thioredoxin regulatory switch on its γ-subunit, which is largely absent in mitochondria.
(C) Only the mitochondrial ATP synthase utilizes a proton gradient; the chloroplast uses a sodium gradient.
(D) The mitochondrial ATP synthase contains a light-harvesting antenna.

2021

176. At which specific point does the Alternative Oxidase (AOX) pathway branch off from the main mitochondrial electron transport chain?
(A) At Complex I (NADH dehydrogenase).
(B) At Cytochrome c.
(C) At Complex IV (Cytochrome c oxidase).
(D) At the Ubiquinone (UQ) pool.

2016

177. Identify the correct statement regarding the thermodynamic efficiency of the Alternative Oxidase (AOX) pathway.
(A) Electron flow from ubiquinol to oxygen via AOX bypasses proton-pumping Complexes III and IV, significantly reducing the ATP yield per NADH oxidized.
(B) AOX pumps massive amounts of protons, generating more ATP than the cytochrome pathway.
(C) AOX perfectly couples electron transport to the direct synthesis of GTP.
(D) AOX operates exclusively in anaerobic conditions.

NODIA

2011

178. Which of the following chemical compounds is classically used in experimental settings to specifically inhibit the Alternative Oxidase (AOX)?
(A) Potassium cyanide (KCN).
(B) Malonate.
(C) Salicylhydroxamic acid (SHAM).
(D) Carbon monoxide (CO).

2015

179. Identify the INCORRECT pair regarding the phenomenon of thermogenesis in plants (e.g., Arum lilies, skunk cabbage).
(A) Primary carbon source — Direct and exclusive assimilation of atmospheric CO_2 in the dark.
(B) Spadix tissue — The specific floral organ where intense thermogenesis occurs.
(C) Heat generation mechanism — Massive flux of electrons through the uncoupled AOX pathway.
(D) Ecological function — Volatilization of odoriferous compounds to attract specific pollinators (e.g., carrion flies).

2003

180. Match the distinct plant respiratory bypasses or uncoupling systems in List I with their defining biochemical characteristics in List II.
List I: (Bypasses or Systems)
P. Alternative Oxidase (AOX)
Q. Plant Uncoupling Proteins (pUCP)
R. Alternative external NAD(P)H dehydrogenase
S. Rotenone-insensitive internal NADH dehydrogenase
List II: (Characteristics)
1. Oxidizes cytosolic NADH directly without pumping protons.
2. Oxidizes matrix NADH without passing through Complex I, lacking proton pumping.
3. Reduces O_2 to water directly from the ubiquinone pool, releasing energy as heat.

4. Dissipates the proton gradient by allowing H^+ re-entry into the matrix, bypassing ATP synthase.

(A) P-3, Q-4, R-1, S-2
(B) P-4, Q-3, R-2, S-1
(C) P-3, Q-1, R-4, S-2
(D) P-1, Q-2, R-3, S-4

2002

181. All of the following are recognized physiological roles of the Alternative Oxidase (AOX) pathway in non-thermogenic plant tissues, EXCEPT:
(A) Preventing the over-reduction of the ubiquinone pool.
(B) Maximizing the strict maximum yield of ATP per molecule of glucose oxidized.
(C) Minimizing the generation of reactive oxygen species (ROS) during stress.
(D) Allowing the continuation of the TCA cycle (to provide carbon skeletons) when ATP demand is low but reducing power is high.

2008

182. Based on the biochemical regulation of AOX, what cellular conditions would result in the highest specific activity of the enzyme?
(A) Highly oxidized ubiquinone pool, total lack of pyruvate, and oxidized AOX dimers with intact disulfide bonds.
(B) Extremely high ATP/ADP ratios and severe depletion of all TCA cycle organic acids.
(C) Highly reduced ubiquinone pool, high matrix pyruvate, and reduced AOX (free sulfhydryl groups).
(D) Total absence of molecular oxygen.

2014

183. What is a common cause and effect relationship observed regarding AOX expression when plant roots are subjected to prolonged chilling stress or phosphate starvation?
(A) Severe stress represses the AOX gene entirely, shifting all flow to the cytochrome pathway to maximize ATP.
(B) Stress permanently converts AOX into a chlorophyll-binding protein.
(C) The plant instantly undergoes apoptosis solely mediated by AOX.
(D) Stress factors induce strong transcriptional upregulation and increased capacity of the AOX pathway to maintain metabolic flexibility and limit oxidative damage.

2002

184. What is the most appropriate description of the physiological significance of "cyanide-resistant respiration" in plants?
(A) It demonstrates the presence of a parallel, non-phosphorylating terminal oxidase (AOX) that ensures electron transport can continue even if the primary cytochrome pathway is compromised.
(B) It proves that plant mitochondria do not contain Cytochrome c oxidase.
(C) It indicates that plants detoxify cyanide by incorporating it into amino acids.
(D) It shows that photosynthesis can run in reverse to provide energy.

2002

185. In whole-plant ecophysiology, dark respiration is often functionally divided into growth and maintenance components. What fundamentally distinguishes maintenance respiration?
(A) It is the energy strictly allocated to synthesizing entirely new biomass and dividing cells.
(B) It is the energy expended to preserve existing biomass, including protein turnover, maintaining ion gradients, and cellular repair.
(C) It is the burst of respiration that occurs exclusively immediately upon illumination.
(D) It represents the carbon completely lost to the soil via root exudation.

2025

186. Identify the INCORRECT statement regarding the mathematical modeling and quantification of plant respiration components.
(A) Total respiration (R_t) is often modeled as the sum of growth respiration (R_g) and maintenance respiration (R_m).
(B) The specific rate of maintenance respiration is entirely independent of environmental temperature.
(C) Maintenance respiration is generally proportional to the total dry weight or protein content of the plant.
(D) Growth respiration is considered proportional to the absolute rate of synthesis of new structural biomass.

2014

187. Among the various cellular processes requiring maintenance energy, which of the following typically accounts for the largest proportion of

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maintenance respiration costs in mature leaf tissue?
(A) Continuous turnover (degradation and resynthesis) of proteins, particularly enzymes like Rubisco.
(B) De novo synthesis of cell wall cellulose.
(C) DNA replication for mitosis.
(D) Synthesis of secondary metabolites to deter massive sudden herbivory.

2003

188. Identify the correct pair associating a phase of plant development with its dominant respiratory component.
(A) Rapidly expanding young leaf — Dominated by maintenance respiration.
(B) Senescing leaf — Dominated by growth respiration.
(C) Mature, fully expanded resting leaf — Dominated by maintenance respiration.
(D) Germinating seed prior to radicle emergence — Exclusively maintenance respiration.

2018

189. All of the following factors generally trigger a significant increase in the rate of maintenance respiration in a plant, EXCEPT:
(A) Increasing ambient temperature (within physiological limits).
(B) Severe salinity stress requiring active ion exclusion.
(C) Exposure to low concentrations of toxic heavy metals requiring repair mechanisms.
(D) A sudden, massive decrease in the availability of all carbon substrates.

2008

190. Consider the following techniques or metrics used by ecophysiologists to estimate or isolate the components of plant respiration:
I. Measuring dark CO_2 efflux during periods of zero growth (e.g., prolonged darkness).
II. Correlating steady-state respiration rates with total plant protein content.
III. Determining the "cost of biosynthesis" based on the known biochemical pathways for synthesizing specific macromolecules.
IV. Using isotopic labeling (e.g., ${}^{13}C$ or ${}^{14}C$) to trace carbon allocation to volatile emissions.
V. The "extrapolation to zero growth" method plotting specific respiration rate against relative growth rate.
Which combination of these methodologies is primarily utilized to estimate the coefficient of maintenance respiration (m)?
(A) I, II and V
(B) III, IV and V
(C) I, III and IV
(D) II, III and V

NODIA

2011

191. If an agronomist monitors the specific respiration rate (moles of CO_2 evolved per gram of dry weight per day) of a corn canopy over its entire lifespan from seedling to senescence, what general trend is predictably observed?
(A) The specific respiration rate remains perfectly constant throughout the life cycle.
(B) The specific respiration rate is highest in young, actively growing seedlings and gradually declines as the proportion of non-metabolically active structural tissue (and reliance solely on maintenance) increases.
(C) The specific respiration rate steadily increases, peaking just before plant death.
(D) The rate drops to zero during the vegetative phase and spikes during flowering.

2013

192. What is the cause and effect of elevated nighttime temperatures on plant carbon balance via maintenance respiration?
(A) High temperatures freeze the mitochondrial membranes, halting respiration and saving carbon.
(B) Elevated temperatures permanently convert all maintenance respiration into growth respiration, resulting in massive gigantism.
(C) High nighttime temperatures activate Rubisco to fix CO_2 in the dark, perfectly offseting respiratory losses.
(D) High temperatures drastically increase the $Q_{\{10\}}$ of maintenance processes, causing excessive consumption of stored daily photosynthates, which can ultimately reduce overall crop yield.

2006

193. The concept of "apparent respiration" (often measured as net CO_2 efflux in the light) is complicated by the fact that true mitochondrial respiration in the light is:
(A) Generally inhibited or reduced compared to dark respiration, partly due to a higher cytosolic ATP/ADP ratio supplied by chloroplasts and alternative internal recycling of CO_2.
(B) Exactly equal to dark respiration under all conditions.

(C) Always at least ten times higher than in the dark due to photorespiration.
(D) Non-existent, as mitochondria completely dissolve in the presence of light.

2015

194. The primary storage form of lipids in plant seeds is the triacylglycerol (TAG). What is the basic chemical structure of a TAG molecule?
(A) Three glycerol molecules esterified to a single fatty acid chain.
(B) Two fatty acids and a phosphate group esterified to glycerol.
(C) A single glycerol backbone esterified to three long-chain fatty acids.
(D) A long-chain alcohol esterified to a single long-chain fatty acid.

2018

195. Identify the correct statement regarding de novo fatty acid synthesis in plant cells.
(A) It takes place primarily in the plastids (chloroplasts or amyloplasts) using acetyl-CoA as the primary building block.
(B) It occurs exclusively in the endoplasmic reticulum.
(C) It requires a massive influx of NADH from the mitochondrion.
(D) It involves the direct degradation of starch into hexanoic acid.

2001

196. In oleaginous seeds, TAGs are stored in specialized organelles called oleosomes (lipid bodies). What uniquely stabilizes the single phospholipid monolayer surrounding the oleosome?
(A) A thick rigid layer of crystalline cellulose.
(B) High concentrations of dissolved Rubisco.
(C) An intricate mesh of actin microfilaments.
(D) Specialized structural amphipathic proteins known as oleosins.

2006

197. Identify the INCORRECT pair regarding the predominant lipid classes and their primary cellular membrane locations in plants.
(A) Galactolipids (e.g., MGDG, DGDG) — Thylakoid membranes of chloroplasts.
(B) Sulfolipids (SQDG) — Exclusively found in the plant central vacuole.
(C) Phosphatidylcholine (PC) — Plasma membrane and outer mitochondrial membrane.
(D) Sterols (e.g., sitosterol) — Plasma membrane.

2006

198. All of the following are distinct enzymes participating directly in the core β-oxidation cycle of fatty acids in plant glyoxysomes, EXCEPT:
(A) Acyl-CoA oxidase.
(B) Multifunctional protein (enoyl-CoA hydratase and 3-hydroxyacyl-CoA dehydrogenase).
(C) Acetyl-CoA carboxylase (ACCase).
(D) 3-Ketoacyl-CoA thiolase.

2003

199. During seed germination, the massive stores of lipid must be converted into mobile sugars (sucrose) to feed the growing seedling. Which specific pathway provides the crucial bypass linking lipid breakdown (acetyl-CoA) to gluconeogenesis?
(A) The Pentose Phosphate Pathway.
(B) The Calvin-Benson cycle.
(C) The Shikimate pathway.
(D) The Glyoxylate cycle, utilizing isocitrate lyase and malate synthase.

2023

200. Select the correct sequential steps of a single turn of the β-oxidation cycle acting on an acyl-CoA molecule in the plant peroxisome/glyoxysome.
(A) Oxidation (introducing a double bond) → Hydration → Second Oxidation (forming a ketone) → Thiolytic cleavage (releasing Acetyl-CoA).
(B) Hydration → Oxidation → Reduction → Thiolytic cleavage.
(C) Cleavage → Hydration → Oxidation → Second Cleavage.
(D) Reduction → Hydration → Oxidation → Condensation.

2023

201. What is the precise cause and effect of upregulating specific fatty acid desaturases (e.g., FAD2, FAD3) in plant cell membranes in response to cold temperatures?
(A) Desaturases remove double bonds, making the membrane more rigid and preventing leakage.
(B) Desaturases introduce cis-double bonds into the fatty acid acyl chains, creating kinks that prevent tight packing, thereby maintaining membrane fluidity and function at lower temperatures.
(C) They immediately cleave all fatty acids into signaling molecules that cause systemic

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acquired resistance.
(D) They convert all membrane lipids into stable starch granules.

2019

202. The enzyme Acetyl-CoA carboxylase (ACCase) is fundamental to plant lipid metabolism. By definition, its primary regulatory role is to:
(A) Synthesize the glycerol backbone for TAGs.
(B) Catalyze the ATP-dependent carboxylation of acetyl-CoA to form malonyl-CoA, the committed first step in de novo fatty acid synthesis.
(C) Catalyze the final cleavage in β-oxidation.
(D) Decarboxylate malate to pyruvate in the bundle sheath.

2008

203. When contrasting the localization of β-oxidation in plant versus animal cells, what is the defining difference?
(A) In plants, it occurs exclusively in peroxisomes/glyoxysomes, whereas in animals, it occurs primarily in mitochondria.
(B) In plants, it occurs in the chloroplast stroma, whereas in animals, it occurs in the Golgi.
(C) In plants, it happens in the cytosol, whereas animals use the rough endoplasmic reticulum.
(D) There is no difference; both strictly use mitochondria.

2022

204. Plant epidermal surfaces are protected by complex lipid-based polymers. Which statement best differentiates the basic chemical composition of cutin from suberin?
(A) Cutin is a pure protein matrix, whereas suberin is a pure carbohydrate.
(B) Cutin is found exclusively in roots, whereas suberin is found exclusively on leaves.
(C) Cutin is a polyester composed primarily of hydroxy and epoxy fatty acids, whereas suberin is a highly complex heteropolymer containing both aliphatic (long-chain fatty acid derivatives) and significant aromatic (phenolic) domains.
(D) Cutin requires extensive nitrogen for its synthesis, whereas suberin does not.

2021

205. Determine the correct ordered arrangement of the generalized stages of epicuticular wax biosynthesis in epidermal cells, and select the matching option.
(A) De novo synthesis of C16/C18 fatty acids in the plastid → Export to the ER → Elongation into Very-Long-Chain Fatty Acids (VLCFAs) → Modification (e.g., decarbonylation to alkanes or reduction to primary alcohols) → Export to the cuticle.
(B) Synthesis of VLCFAs in the plastid → Export to the vacuole → Breakdown to C16 → Secretion to the cell wall.
(C) Elongation in the Golgi → Reduction to alcohols → Export to plastid → Formation of cutin.
(D) Decarbonylation in the cytosol → Import into plastid → Elongation to VLCFAs → Exudation via stomata.

2002

206. The Casparian strip is a critical barrier in the plant root endodermis regulating nutrient and water uptake. Which lipid-based polymer is a primary structural component of the Casparian strip?
(A) Sporopollenin.
(B) Lignin only.
(C) Suberin.
(D) Soluble cuticular waxes.

NODIA

2012

207. Identify the INCORRECT statement regarding the crystallization of epicuticular waxes on the leaf surface.
(A) Waxes are thought to self-assemble into diverse 3D microstructures (e.g., tubules, plates, rodlets) upon reaching the cuticle.
(B) Waxes are exuded strictly as fully formed microscopic solid crystals directly from the Golgi apparatus onto the leaf surface.
(C) The specific 3D structure of the wax crystals strongly influences the hydrophobicity and light-reflecting properties (glaucousness) of the leaf.
(D) The chemical composition (e.g., prevalence of secondary alcohols vs primary alcohols) dictates the predominant crystal form.

2022

208. Identify the correct pair matching the specialized surface polymer with its primary biological function.
(A) Cutin — Forms a massive subterranean physical barrier against root herbivory.
(B) Sporopollenin — Acts as a highly water-soluble transport lipid in the phloem.
(C) Epicuticular wax — Promotes maximum water adhesion (wetting) to the leaf surface

for absorption.

(D) Suberin — Restricts apoplastic water movement in the endodermis and seals wounded tissues.

2007

209. All of the following are established physiological or ecological functions of the plant surface lipid layers (cuticle and epicuticular waxes), EXCEPT:

(A) Serving as the primary site for active absorption of macronutrients from the atmosphere.

(B) Minimizing non-stomatal transpirational water loss.

(C) Attenuating harmful ultraviolet (UV) radiation.

(D) Providing a self-cleaning (Lotus effect) surface that repels water and washes away fungal spores.

2016

210. Consider the following characteristics associated with suberin lamellae:

I. Contains a substantial polyaromatic domain structurally related to lignin.

II. Contains a polyaliphatic domain consisting of extremely long-chain fatty acid derivatives.

III. Deposited entirely on the outer surface of the primary cell wall facing the external environment.

IV. Functions to restrict the diffusion of oxygen in specialized structures like root nodules.

V. Highly impermeable to water and solutes.

Which of the above statements accurately describe suberized cell walls?

(A) I, II, IV and V

(B) I, II, III and V

(C) II, III, IV and V

(D) I, III, IV and V

2004

211. Based on current models, how do highly hydrophobic cuticular wax components synthesize in the ER manage to cross the hydrophilic aqueous apoplast to reach the expanding cuticle?

(A) They are transported across the plasma membrane by ABC transporters and shuttled through the cell wall by Lipid Transfer Proteins (LTPs).

(B) They freely diffuse through the water without any carriers.

(C) They are packaged into giant starch granules that are pushed out of the cell.

(D) The cell wall undergoes programmed cell death to reveal the lipid layers beneath.

2008

212. What is the most appropriate description of the role of Very-Long-Chain Fatty Acids (VLCFAs, $> C_{\{20\}}$) in epicuticular wax production?

(A) They serve strictly as signaling molecules to initiate stomatal development.

(B) They act as powerful detergents that dissolve the cuticle during rapid leaf expansion.

(C) They are solely utilized for ATP production in epidermal mitochondria.

(D) They are the direct obligate precursors for the vast majority of wax components, including alkanes, secondary alcohols, and wax esters.

2007

213. The Shikimate pathway is arguably one of the most crucial metabolic pathways in plants. It provides the central carbon skeleton for the synthesis of which three essential aromatic amino acids?

(A) Leucine, Isoleucine, and Valine.

(B) Phenylalanine, Tyrosine, and Tryptophan.

(C) Serine, Glycine, and Cysteine.

(D) Proline, Arginine, and Histidine.

2005

214. Identify the correct statement regarding the subcellular compartmentalization of the two major pathways generating the 5-carbon isoprenoid building block, isopentenyl diphosphate (IPP).

(A) Both the Mevalonate (MVA) pathway and the MEP (DOXP) pathway are localized strictly in the cytosol.

(B) The MEP pathway occurs in the mitochondrion, and the MVA pathway is in the vacuole.

(C) The MVA pathway is localized in the cytosol/ER, while the MEP pathway is localized in the plastids.

(D) IPP is absorbed exclusively from the soil; plants cannot synthesize it de novo.

2023

215. The universally applied herbicide glyphosate (Roundup) is highly lethal to most plants. What is its exact molecular mechanism?

(A) It irreversibly binds to and inhibits Photosystem II.

(B) It uncouples mitochondrial electron transport.

(C) It destroys the structural integrity of the cell

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wall by inhibiting cellulose synthase.
(D) It competitively inhibits 5-enolpyruvylshikimate-3-phosphate (EPSP) synthase, a key enzyme in the Shikimate pathway.

2005

216. Identify the INCORRECT pair connecting a secondary metabolite class to its primary biosynthetic pathway or intermediate.
(A) Tannins — Derived exclusively from the direct degradation of unbroken fatty acids.
(B) Monoterpenes — MEP pathway (via GPP).
(C) Lignin — Shikimate pathway (via Phenylalanine).
(D) Sesquiterpenes — Mevalonate (MVA) pathway (via FPP).

2006

217. Plant secondary metabolites are synthesized from primary carbon metabolism precursors. All of the following are major distinct starting points for diverse secondary metabolite pathways, EXCEPT:
(A) Erythrose-4-phosphate and Phosphoenolpyruvate (Shikimate pathway).
(B) RuBP directly bypassing the Calvin cycle to form alkaloids.
(C) Acetyl-CoA (MVA and Malonate pathways).
(D) Pyruvate and Glyceraldehyde-3-phosphate (MEP pathway).

2024

218. In terpene biosynthesis, the structural diversity is astonishing. Conceptually, how are the basic five-carbon isoprene units (IPP and DMAPP) assembled by prenyltransferases to form larger chains?
(A) They are linked via highly random, uncoordinated covalent cross-linking.
(B) They undergo a highly ordered, sequential "head-to-tail" condensation to form generic prenyl diphosphates (e.g., GPP, FPP, GGPP).
(C) They are exclusively polymerized linearly "tail-to-tail" to form polyisoprenes like rubber.
(D) They are cyclized instantly before any condensation occurs.

2017

219. What is the typical cause and effect relationship governing the regulation of the MEP pathway in green leaves?
(A) Light stimulates photosynthesis, generating plastidic pyruvate, GAP, and reducing power (ferredoxin/NADPH), which strongly upregulate the MEP pathway flux to support massive synthesis of carotenoids and phytol.
(B) Exposure to light strongly represses the MEP pathway to conserve carbon for respiration.
(C) Severe drought stress instantly converts all MEP enzymes into the MVA pathway enzymes.
(D) High nitrogen fertilization blocks the MEP pathway completely, stopping all growth.

2023

220. Phenylalanine ammonia-lyase (PAL) is arguably the most extensively studied enzyme in plant secondary metabolism. By definition, it catalyzes the reaction that:
(A) Adds an ammonia group to cinnamic acid to form phenylalanine.
(B) Cleaves the aromatic ring of phenylalanine to form linear fatty acids.
(C) Catalyzes the non-oxidative deamination of L-phenylalanine to form trans-cinnamic acid and free ammonia, representing the gateway to all phenylpropanoid metabolism.
(D) Hydrolyzes the peptide bonds in proteins rich in phenylalanine.

2002

221. When comparing the biosynthesis of different classes of terpenes, which statement is generally true regarding the origin of their precursors in a typical plant cell?
(A) Volatile monoterpenes (C10) are primarily formed in the cytosol.
(B) The plastid exclusively synthesizes sterols and brassinosteroids.
(C) There is absolutely no cross-talk or exchange of IPP intermediates across the plastid envelope.
(D) Sesquiterpenes (C15) and triterpenes (C30) like sterols are primarily synthesized from MVA-derived precursors (FPP) in the cytosol/ER.

2010

222. The enormous class of terpenes is systematically categorized based on the number of 5-carbon (isoprene) units they contain. According to this classification, a diterpene contains:
(A) 10 carbon atoms.
(B) 15 carbon atoms.
(C) 20 carbon atoms.
(D) 30 carbon atoms.

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2018

223. Identify the INCORRECT statement regarding the structural composition of lignin, a complex phenolic polymer.

(A) It is formed primarily by the random oxidative coupling of monolignol radicals.

(B) The three main monolignol building blocks are strictly straight-chain saturated fatty alcohols.

(C) The proportions of p-hydroxyphenyl (H), guaiacyl (G), and syringyl (S) units vary widely between gymnosperms and angiosperms.

(D) Lignin provides immense mechanical rigidity and waterproofing to xylem vessels.

2023

224. Cyanogenic glycosides are potent defensive nitrogen-containing secondary metabolites. How does their toxic mechanism operate upon tissue damage by an herbivore?

(A) They act as heavy metal chelators that strip iron from the herbivore's blood.

(B) They immediately polymerize into an indigestible plastic-like resin within the herbivore's gut.

(C) They emit a strong volatile signal that repels the herbivore before it even bites the leaf.

(D) Spatial compartmentalization is disrupted, allowing endogenous β-glycosidases and hydroxynitrile lyases to sequentially cleave the glycoside, rapidly releasing toxic hydrogen cyanide (HCN) gas.

2007

225. Identify the correct pair associating a well-known plant alkaloid with its specific pharmacological or ecological effect.

(A) Morphine — Synthesized by the opium poppy, acts as a potent analgesic acting on the central nervous system.

(B) Nicotine — Acts as a powerful natural herbicide that kills competing plants.

(C) Caffeine — Acts strictly as a fungicide on the leaf surface.

(D) Vinblastine — Promotes rapid cell division and is used as a fertilizer.

2010

226. All of the following are distinct sub-classes of plant phenolic compounds, EXCEPT:

(A) Flavonoids.

(B) Anthocyanins.

(C) Glucosinolates.

(D) Coumarins.

2005

227. In the context of plant defense, the "mustard oil bomb" refers to the highly reactive system found in the Brassicaceae family. Conceptually, this system is based on:

(A) The spatial separation of stable glucosinolates (in vacuoles) and the enzyme myrosinase (in specialized idioblasts); tissue crushing mixes them, producing toxic, pungent isothiocyanates.

(B) The sudden, explosive physical rupturing of trichomes filled with concentrated sulfuric acid.

(C) The spontaneous combustion of volatile monoterpenes on hot days.

(D) The rapid synthesis of massive amounts of hydrogen peroxide targeted at invading fungal hyhyphae.

2016

228. What is the cause and effect governing the production of phytoalexins in plants?

(A) They are constitutively synthesized in enormous quantities throughout the life of the plant to provide an impenetrable permanent shield against all herbivores.

(B) They are synthesized purely in response to severe drought, acting to plug open stomata.

(C) They are produced in the roots to attract nitrogen-fixing rhizobia.

(D) Upon perception of pathogen elicitors, defensive signaling pathways are activated, leading to the rapid, localized de novo synthesis of these antimicrobial compounds to halt the infection.

NODIA

2019

229. Tannins are high-molecular-weight phenolic polymers broadly classified into two categories: hydrolyzable and condensed. By definition, condensed tannins (proanthocyanidins) are:

(A) Polymers of simple phenolic acids, like gallic acid, linked to a central glucose core, easily broken down by mild acids.

(B) Polymers of flavonoid units (e.g., catechin) linked by resilient carbon-carbon bonds, requiring harsh oxidative conditions for cleavage.

(C) Short-chain linear peptides that bind strongly to herbivore digestive enzymes.

(D) Highly volatile aromatic compounds responsible for the scent of ripening fruit.

2015

230. Which description is the most appropriate representation of the complex ecological role of certain specific volatile terpenes emitted by a leaf during active caterpillar feeding?

(A) They serve as an internal nutrient reserve that is mobilized to repair tissue damage.

(B) They act directly as a powerful, immediate contact poison that instantly kills the caterpillar.

(C) They act as "indirect defense" signals that attract parasitic wasps or predatory mites to prey on the caterpillar.

(D) They condense on the leaf surface to form a thick, waxy, and entirely impenetrable physical barrier to prevent further feeding.

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ANSWERS

1. (A) Energy is not created or destroyed, but transformed from radiant energy into chemical bonds during photosynthesis.
The First Law of Thermodynamics, also known as the Law of Conservation of Energy, states that energy cannot be created or destroyed. In the context of plant biology and photosynthesis, solar energy is captured by pigments and transformed into chemical energy stored within the covalent bonds of organic molecules like glucose.

2. (C) By coupling it to an exergonic reaction with a larger negative ΔG, like ATP hydrolysis.
Biological reactions with a positive standard Gibbs free energy change are thermodynamically unfavorable. To proceed in the forward direction within a plant cell, these endergonic reactions must be coupled to highly exergonic processes. Typically, the hydrolysis of ATP provides enough negative free energy to drive the overall coupled reaction toward the formation of products.

3. (A) Addition of solutes to pure water increases its chemical potential above zero.
The chemical potential of water represents its partial molar free energy. For pure water at standard temperature and pressure, this value is defined as zero. Adding solutes decreases the mole fraction of water and reduces its chemical potential to negative values. Therefore, solutes always lower the water potential rather than increasing it above the reference level.

4. (D) The activation energy of the electron transfer (E_a).
The Nernst equation relates the reduction potential of an electrochemical cell to the standard electrode potential, temperature, and activities of the chemical species. While it incorporates the gas constant, temperature, and Faraday constant, it does not include activation energy. Activation energy is a kinetic parameter determining reaction rates, whereas the Nernst equation addresses thermodynamic equilibrium potentials.

5. (B) It reduces the magnitude of the negative ΔG for hydrolysis, slowing down ATP-dependent processes.
The actual free energy change for ATP hydrolysis depends on the concentrations of ATP, ADP, and inorganic phosphate. A highly elevated ATP/ADP ratio shifts the equilibrium, resulting in a more negative Gibbs free energy change. This increase in the driving force enhances the energy available for various cellular processes, including active transport and metabolic biosynthesis.

6. (C) The standard chemical state assumes $[H^+]$ is 1 M (pH 0), whereas the biological state assumes $[H^+]$ is $10^{\{-7\}}$ M (pH 7).
In standard thermodynamics, the chemical state assumes a reactant concentration of one molar, which corresponds to a pH of zero for protons. However, biological systems operate near neutrality. Consequently, the standard biological state is defined at a pH of seven, representing a proton concentration of ten to the power of negative seven molar for consistency.

7. (D) Fructose-1,6-bisphosphatase.
The photosynthetic electron transport chain involves several redox-active components that shuttle electrons from water to NADP+. Plastoquinone, ferredoxin, and the cytochrome complex are integral parts of this pathway. In contrast, fructose-one-six-bisphosphatase is a key regulatory enzyme within the Calvin-Benson cycle responsible for carbon fixation and regeneration, rather than direct light-driven electron transfer processes.

8. (A) Entropy - Joules per Kelvin per mole.
Thermodynamics utilizes specific units for various physical quantities to maintain consistency in calculations. Entropy measures the degree of disorder or randomness in a system and is expressed in Joules per Kelvin per mole. Other variables like enthalpy are measured in Joules per mole, while redox potential is measured in volts, reflecting electrical driving forces.

NODIA

9. (B) The sum of the chemical concentration gradient and the electrical potential difference across the membrane.
The electrochemical potential gradient across a biological membrane accounts for two distinct forces acting on an ion. It is the summation of the chemical concentration gradient and the electrical potential difference. This combined force determines the direction of spontaneous movement for charged solutes, such as protons or potassium ions, across the lipid bilayer in plant cells.

10. (D) A is false but R is true.
The Enzyme Commission classification system is a systematic method for naming enzymes based on the specific chemical reactions they catalyze. It does not use alphabetical order but rather assigns a unique four-digit code. These digits sequentially represent the major class, subclass, sub-subclass, and the specific entry number, providing a rigorous and universal nomenclature for biochemical research.

11. (A) The rate of enzyme-substrate complex formation equals its rate of breakdown under steady-state conditions.
The Michaelis-Menten model for enzyme kinetics relies on the steady-state assumption during the initial phase of the reaction. This assumption posits that the concentration of the enzyme-substrate complex remains constant over time. Specifically, the rate at which the complex is formed from free enzyme and substrate equals the rate at which it breaks down into products.

12. (D) EC 6 (Ligases).
Enzymes are categorized into six main classes by the Enzyme Commission based on their reaction mechanisms. Class six, known as ligases, includes enzymes that catalyze the joining of two molecules. This process typically requires energy input, which is provided by the concomitant hydrolysis of a high-energy phosphate bond, such as that found in adenosine triphosphate molecules.

13. (D) The slope of the line is equal to $\frac{K_m}{V_{\max}}$.
The Lineweaver-Burk plot is a double-reciprocal representation of Michaelis-Menten kinetics, transforming the hyperbolic curve into a straight line. In this graphical method, the y-intercept equals one over the maximum velocity, while the x-intercept equals negative one over the Michaelis constant. The slope of the resulting linear equation is mathematically defined as the ratio of these two constants.

14. (C) Uncompetitive inhibition — Both apparent K_m and $V_{\{\max\}}$ increase proportionally.
Uncompetitive inhibition occurs when an inhibitor binds only to the enzyme-substrate complex. This mechanism effectively reduces both the maximum velocity and the Michaelis constant because the removal of the complex shifts the equilibrium according to Le Chatelier's principle. Therefore, saying that both parameters increase proportionally is incorrect, as both values actually decrease in the presence of an uncompetitive inhibitor.

15. (B) It binds exclusively to the enzyme-substrate (ES) complex, not the free enzyme.
Uncompetitive inhibition is a distinct form of reversible enzyme inhibition. Unlike competitive inhibitors that vie for the active site, uncompetitive inhibitors bind exclusively to the enzyme-substrate complex rather than the free enzyme. This binding prevents the conversion of substrate to product and lowers the effective concentration of the complex, altering both the affinity and the maximum reaction rate.

16. (D) The maximum number of substrate molecules converted to product per active site per unit time at saturation.
The turnover number, denoted as k-cat, provides a measure of the catalytic efficiency of an individual enzyme molecule. It represents the maximum number of substrate molecules that a single active site can convert into products within a specific unit of time. This value is calculated when the enzyme is fully saturated with substrate, reflecting its intrinsic catalytic capacity.

17. (A) Allosteric effectors induce rapid, reversible conformational changes to respond to fluctuating cellular metabolite levels.
Allosteric regulation allows plants to rapidly adjust enzyme activity in response to changing metabolic demands. Effectors bind non-covalently to sites other than the active site, inducing reversible conformational changes. This mechanism is significantly faster than covalent modification or protein synthesis, enabling the cell to maintain homeostasis by sensing

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fluctuations in the levels of various metabolites or signaling molecules.

18. (C) An enzyme that lacks its required organic or inorganic cofactor and is catalytically inactive.
Enzymes often require non-protein components, such as metal ions or organic molecules, to perform their catalytic functions. An apoenzyme refers specifically to the protein portion of such an enzyme when it is not bound to its required cofactor. In this state, the enzyme is catalytically inactive and must bind its partner to form a functional holoenzyme.

19. (A) The total concentration of the enzyme added to the assay.
The Michaelis constant is an intrinsic property of an enzyme reflecting its affinity for a specific substrate under defined conditions. It is influenced by environmental factors such as temperature, pH, and the specific amino acid sequence of the active site. However, the total concentration of the enzyme added to an assay does not change the value of this kinetic constant.

20. (A) P-2, Q-1, R-3, S-4
Plant transcription factor families are characterized by specific structural domains. WRKY factors contain a conserved heptapeptide sequence, while bZIP factors utilize a leucine zipper for DNA binding during stress signaling. MYB factors possess helix-turn-helix motifs, and NAC factors are plant-specific regulators essential for development. These domains allow for precise control of gene expression in various physiological contexts.

21. (B) It degrades polyubiquitinated proteins via ATP-dependent proteolysis in the cytosol and nucleus.
The twenty-six-S proteasome is a large multi-protein complex responsible for the selective degradation of intracellular proteins. It specifically targets proteins that have been tagged with polyubiquitin chains. This ATP-dependent process occurs within the cytosol and nucleus, allowing the plant to remove misfolded, damaged, or regulatory proteins that are no longer needed, thereby maintaining cellular proteostasis and metabolic regulation.

22. (C) It transfers the activated ubiquitin to the target protein directly or to an E3 ligase.
The ubiquitin-proteasome system involves a cascade of three enzymes. The E-two enzyme, or ubiquitin-conjugating enzyme, receives the activated ubiquitin molecule from the E-one activating enzyme via a thioester bond. It then transfers this ubiquitin to the target protein, often in coordination with an E-three ligase, which provides the necessary sugar specificity for the tagging process in plants.

23. (D) The structural diversity and substrate recognition domains of various E3 ubiquitin ligases.
High substrate specificity in the ubiquitin-mediated degradation pathway is primarily determined by the E-three ubiquitin ligases. Plants possess a vast diversity of these enzymes, each containing specific domains designed to recognize and bind particular target proteins. This diversity ensures that only appropriate substrates are polyubiquitinated and subsequently delivered to the proteasome for degradation during growth and stress responses.

24. (A) Chloroplasts utilize 80S ribosomes identical to those found in the cytosol for synthesizing photosynthetic proteins.
Translation in plant cells occurs in the cytosol, mitochondria, and chloroplasts. Cytosolic ribosomes are eighty-S structures composed of sixty-S and forty-S subunits. In contrast, chloroplasts and mitochondria contain seventy-S ribosomes, which are structurally and functionally more similar to prokaryotic ribosomes. Therefore, stating that chloroplasts utilize the same eighty-S ribosomes as the cytosol for protein synthesis is incorrect.

25. (B) It facilitates the formation of a high-energy thioester bond between E1 and the C-terminus of ubiquitin.
The initial step in the ubiquitination pathway is the activation of ubiquitin by the E-one enzyme. This process requires ATP hydrolysis to facilitate the formation of a high-energy thioester bond between the carboxyl terminus of ubiquitin and a cysteine residue on the enzyme. This activation provides the energy necessary for subsequent transfer steps to E-two and eventually the target protein.

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26. (B) The N-end rule pathway.
The N-end rule pathway is a specialized proteolytic system that relates the metabolic stability of a protein to the identity of its amino-terminal residue. Certain residues at the N-terminus act as degradation signals, or degrons, which are recognized by specific E-three ligases. This mechanism allows the cell to precisely control the half-life of various regulatory and structural proteins.

27. (A) Shine-Dalgarno sequence.
RNA polymerase Two recognizes several core promoter elements in plant genomes, including the TATA box, the initiator element, and pyrimidine-rich patches. These elements facilitate the assembly of the pre-initiation complex. The Shine-Dalgarno sequence, however, is a prokaryotic ribosomal binding site found in bacteria and chloroplasts, and it is not a feature of eukaryotic nuclear core promoters.

28. (C) Lysine-48 (K48) linkage.
Ubiquitin can form various types of polyubiquitin chains through its lysine residues. The specific linkage determines the fate of the tagged protein. Chains linked through lysine-forty-eight are the canonical signal recognized by the twenty-six-S proteasome for targeting the protein for ATP-dependent degradation. Other linkages, such as lysine-sixty-three, are often involved in non-proteolytic processes like signaling and DNA repair.

29. (D) Chloroplastic mRNAs often lack a 5' cap and poly-A tail, relying on Shine-Dalgarno-like sequences for ribosome binding.
Translation in chloroplasts exhibits several prokaryotic characteristics that distinguish it from cytosolic translation. Chloroplastic messenger RNAs typically lack the five-prime cap and poly-A tail found on nuclear-encoded transcripts. Instead, they often utilize Shine-Dalgarno-like sequences to recruit the seventy-S ribosomes to the initiation site, reflecting the endosymbiotic evolutionary origin of the chloroplast organelle within the plant cell.

30. (A) I and II
Chloroplasts possess a complex internal membrane system organized into grana and stroma lamellae. Grana consist of stacked thylakoids enriched in Photosystem Two. Stroma lamellae connect these stacks and contain Photosystem One and ATP synthase. However, the inner envelope membrane is not highly permeable; it contains specific transporters that regulate the movement of ions and metabolites between the stroma and cytosol.

31. (B) Chlorophyll *b* has a formyl group (-CHO) instead of a methyl group ($-CH_3$) on the porphyrin ring II.
Chlorophyll molecules consist of a porphyrin ring with a central magnesium ion and a long phytol tail. The primary structural difference between chlorophyll a and b lies in the side chain on the second ring of the porphyrin. Chlorophyll b has a formyl group where chlorophyll a has a methyl group. This subtle change significantly shifts the absorption spectrum of the pigment.

32. (D) Beta-carotene — absorbs strongly in the blue region (400-500 nm).
Different photosynthetic pigments absorb light at characteristic wavelengths within the visible spectrum. Beta-carotene is a carotenoid that absorbs strongly in the blue region, typically between four hundred and five hundred nanometers. Chlorophylls absorb mostly in the blue and red regions, leaving the green portion of the spectrum to be reflected or transmitted, which gives plants their appearance.

33. (A) The relative effectiveness of different wavelengths of light in driving the overall photosynthetic process.
The action spectrum of photosynthesis depicts the rate of the process as a function of the wavelength of light. By comparing this to the absorption spectra of individual pigments, researchers can determine the relative effectiveness of different wavelengths in driving photochemistry. This provides critical insights into which pigments are primarily responsible for energy capture and transfer within the light-harvesting apparatus.

34. (C) Cytochrome b6f complexes are exclusively restricted to the stroma lamellae.
Thylakoid membranes are organized into appressed grana and non-appressed stroma lamellae. Photosystem Two is concentrated in the grana, while Photosystem One and ATP synthase are located in the stroma lamellae to allow access to the stroma. The cytochrome b-six-f complex, however, is distributed throughout both regions, facilitating electron transfer between the spatially

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separated photosystems via mobile carriers like plastoquinone.

35. (A) Inability to synthesize the tetrapyrrole ring center, causing chlorosis and impaired light absorption.
Magnesium is the central atom in the porphyrin ring of chlorophyll molecules and is essential for their synthesis. A severe deficiency in magnesium prevents the plant from producing enough chlorophyll, leading to interveinal chlorosis and a significant reduction in light absorption capacity. This lack of pigment directly impairs the photochemical efficiency of the plant, causing stunted growth and reduced yields.

36. (D) It is a peripheral antenna system associated with PSII in grana to capture and funnel excitation energy.
Light Harvesting Complex Two is a peripheral antenna system primarily associated with Photosystem Two in the grana thylakoids. Its main role is to capture photons and funnel the resulting excitation energy to the reaction center. This complex can also undergo reversible phosphorylation to move between photosystems during state transitions, helping the plant balance the excitation energy between photosystems.

37. (B) Phycocyanin.
Higher plants utilize several accessory pigments to broaden the range of light wavelengths used for photosynthesis, including chlorophyll b and various carotenoids like neoxanthin and lutein. Phycocyanin is a phycobiliprotein pigment found in cyanobacteria and red algae but is not present in the light-harvesting systems of higher plants, which instead rely on the chlorophyll-protein complexes.

38. (C) The non-radiative transfer of excitation energy from a donor pigment to an acceptor pigment through dipole-dipole interactions.
Resonance energy transfer is the mechanism by which excitation energy is moved through the antenna pigments toward the reaction center. It involves a non-radiative transfer of energy from an excited donor molecule to a nearby acceptor molecule through long-range dipole-dipole interactions. This process is highly efficient and does not involve the physical transfer of electrons or the emission of light.

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39. (D) Photosynthesis requires the synergistic cooperation of two distinct photosystems driven by different wavelengths of light.
The red drop effect refers to the sharp decline in photosynthetic efficiency at wavelengths longer than six hundred and eighty nanometers. Emerson discovered that adding shorter-wavelength light restored efficiency, a phenomenon known as the enhancement effect. These observations led to the conclusion that photosynthesis requires the synergistic cooperation of two distinct photosystems, each driven by light of different peak absorption wavelengths.

40. (B) II and III
Components of the photosynthetic electron transport chain vary in their solubility and location. The plastoquinone pool and the cytochrome b-six-f complex are integral parts of the thylakoid lipid bilayer. In contrast, the oxygen-evolving complex is a protein cluster associated with the luminal surface of Photosystem Two, and ferredoxin is a soluble protein located in the chloroplast stroma that carries electrons.

41. (B) The maximum wavelength of light absorption in nanometers for this specific dimer.
The special pair of chlorophyll a molecules in the reaction center of Photosystem Two is designated as P680. The number six hundred and eighty refers to the wavelength in nanometers where the absorption of this specific dimer is maximal. This absorption triggers the primary charge separation, moving an electron from the pigment to the primary acceptor and initiating the electron transport process.

42. (B) It catalyzes the oxidation of two water molecules to yield one molecule of O_2, four protons, and four electrons.
The oxygen-evolving complex is located on the luminal side of the thylakoid membrane and is associated with Photosystem Two. It contains a manganese-calcium cluster that catalyzes the oxidation of water. In this multi-step process, two water molecules are split to produce one molecule of oxygen gas, four protons released into the lumen, and four electrons that refill the reaction center.

43. (A) Two electrons and two protons.
Plastoquinone is a mobile, lipophilic electron carrier within the thylakoid membrane. To be fully reduced to plastoquinol, one molecule

of plastoquinone accepts two electrons from the Photosystem Two reaction center and two protons from the chloroplast stroma. This transition allows it to move through the membrane and deliver electrons to the cytochrome b-six-f complex while contributing to the proton gradient.

44. (C) It recycles electrons from Ferredoxin to the Cytochrome b6f complex, generating ATP without NADPH or O_2.
Cyclic electron transport involves the movement of electrons from ferredoxin back to the cytochrome b-six-f complex and then to Photosystem One. This pathway bypasses the reduction of NADP+ and the splitting of water at Photosystem Two. Consequently, it generates a proton gradient for ATP synthesis without producing oxygen or NADPH, helping to balance the cellular ratio of ATP to reducing power.

45. (D) Pheophytin — Intermembrane space of the chloroplast envelope.
The components of the photosynthetic electron transport chain are precisely localized. Plastocyanin resides in the thylakoid lumen, while ferredoxin is in the stroma. Plastoquinone is located within the thylakoid membrane interior. Pheophytin, the primary electron acceptor of Photosystem Two, is located within the reaction center complex in the thylakoid membrane, not in the intermembrane space of the chloroplast envelope.

46. (C) It binds to the QB site of the D1 protein in PSII, preventing electron transfer to the plastoquinone pool.
The herbicide DCMU, also known as diuron, is a potent inhibitor of photosynthetic electron transport. It acts by binding to the Q-B binding site of the D1 protein within the Photosystem Two reaction center. This binding prevents plastoquinone from associating with the complex, effectively blocking the flow of electrons from the reaction center to the plastoquinone pool and halting the process.

47. (B) Tyrosine residue (TyrZ).
Photosystem One contains several integral components, including the P700 reaction center, phylloquinone, and multiple iron-sulfur clusters. These work together to transfer electrons to ferredoxin. The tyrosine residue known as Tyr-Z is an electron donor found in Photosystem Two, where it bridges the transfer of electrons from the oxygen-evolving complex to the oxidized P680 reaction center, rather than Photosystem One.

48. (D) It allows the transfer of two protons from the stroma to the lumen for every one electron passing through the complex, increasing the proton motive force.
The Q-cycle is a mechanism operating within the cytochrome b-six-f complex that enhances the efficiency of proton pumping. For every electron that passes through the complex toward Photosystem One, the cycle facilitates the transfer of two protons from the stroma to the thylakoid lumen. This effectively increases the proton motive force, leading to a higher yield of ATP per electron moved.

49. (A) It contains a reaction center composed of PsaA and PsaB heterodimers, tightly integrated with a large built-in core antenna system.
Photosystem One is a massive integral membrane protein complex. Its core reaction center is composed of a heterodimer of the PsaA and PsaB proteins. Unlike Photosystem Two, Photosystem One has an extensively integrated core antenna system containing many chlorophyll and carotenoid molecules. This architecture allows it to capture light and reduce ferredoxin with high efficiency, operating as a large monomeric unit.

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50. (A) Both A and R are true and R is the correct explanation of A.
The Mehler reaction involves the reduction of molecular oxygen by electrons from Photosystem One. This process acts as a photoprotective mechanism by serving as an alternative electron sink when light intensity exceeds the capacity of the Calvin cycle. By maintaining electron flow, it prevents the over-reduction of carriers and helps dissipate excess energy, ultimately converting the oxygen back to water through enzymatic scavenging.

51. (A) The splitting of water at PSII to generate electrons, which eventually reduce O_2 back to water via PSI and ROS scavenging enzymes.
The water-water cycle refers to the process where water is split at Photosystem Two to provide electrons, which eventually reduce molecular oxygen back to water at Photosystem One. This cycle incorporates the action of reactive oxygen species scavenging enzymes like superoxide

dismutase and ascorbate peroxidase. It serves as a photoprotective sink for excess electrons while maintaining the proton gradient for ATP synthesis.

52. (D) The cycle operates in the thylakoid lumen and is activated by a high luminal pH (alkaline conditions).
The xanthophyll cycle involves the reversible interconversion of carotenoid pigments to dissipate excess light energy. Under high light, violaxanthin is converted to zeaxanthin via antheraxanthin, a process catalyzed by violaxanthin de-epoxidase. This enzyme is activated by the acidification of the thylakoid lumen, which occurs when proton pumping is high. Therefore, the cycle is triggered by low luminal pH rather than alkaline conditions.

53. (B) Acidification of the thylakoid lumen due to excessive proton pumping.
Non-photochemical quenching is a vital mechanism that protects plants from high-light damage. The largest and fastest component, known as energy-dependent quenching, is triggered by the acidification of the thylakoid lumen. When the rate of electron transport exceeds the rate of ATP consumption, protons accumulate, lowering the luminal pH. This acidity activates specific proteins and enzymes that facilitate the dissipation of energy as heat.

54. (C) It catalyzes the disproportionation of superoxide radicals into hydrogen peroxide and molecular oxygen.
Superoxide dismutase is a primary antioxidant enzyme in plant cells. It catalyzes the disproportionation, or dismutation, of the superoxide radical, which is a common byproduct of electron transport. In this reaction, two superoxide molecules are converted into one molecule of hydrogen peroxide and one molecule of oxygen. This prevents the accumulation of the highly reactive superoxide radical and limits subsequent oxidative damage.

55. (D) Hydrogen peroxide (H_2O_2) — Ascorbate peroxidase (APX).
Plants utilize a suite of enzymes to neutralize different reactive oxygen species. Superoxide dismutase handles the superoxide radical, while catalase and various peroxidases detoxify hydrogen peroxide. In the chloroplast, ascorbate peroxidase is the primary enzyme responsible for reducing hydrogen peroxide to water using ascorbate as an electron donor, playing a central role in the ascorbate-glutathione cycle for maintaining redox homeostasis.

56. (A) Excessive excitation leads to oxidative damage and targeted degradation of the D1 reaction center protein.
Photoinhibition occurs when plants are exposed to light intensities that overwhelm their photoprotective mechanisms. In Photosystem Two, this leads to the generation of reactive oxygen species that cause oxidative damage to the reaction center. Specifically, the D1 protein is targeted for degradation. The plant must then repair the damage by synthesizing new D1 proteins and reassembling the complex to restore photosynthetic activity.

57. (B) Photorespiratory synthesis of glycolate.
Plants have evolved various strategies to manage reactive oxygen species, including the use of antioxidants like tocopherols and the ascorbate-glutathione cycle. Carotenoids also play a role by quenching triplet chlorophyll. Photorespiration can dissipate excess energy but the specific synthesis of glycolate is a byproduct of the oxygenase activity of Rubisco and is not a direct mechanism for neutralizing ROS already present in the chloroplast.

58. (B) Violaxanthin de-epoxidase will activate, increasing zeaxanthin levels to dissipate heat.
When a plant is moved from shade to full sunlight, it experiences a sudden excess of excitation energy. This leads to rapid acidification of the thylakoid lumen. Low pH activates the enzyme violaxanthin de-epoxidase, which converts the pigment violaxanthin into zeaxanthin. Zeaxanthin then facilitates the safe dissipation of the excess energy as heat, protecting the photosynthetic apparatus from potential oxidative damage.

59. (A) Eight large subunits and eight small subunits (L_8S_8).
The Rubisco holoenzyme found in higher plants is a large complex designated as Form One. It consists of sixteen subunits in total, organized into eight large subunits and eight small subunits. The large subunits contain the catalytic active sites and are encoded by the chloroplast genome, while the small subunits are encoded by nuclear genes and imported into the chloroplast to assist.

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60. (A) P-2, Q-4, R-1, S-3
Rubisco activity is controlled by multiple mechanisms. Carbamylation involves the binding of carbon dioxide and magnesium to a specific lysine residue. Rubisco activase acts as a catalytic chaperone to remove inhibitory sugar phosphates like RuBP from uncarbamylated sites. CA1P is a transition-state analog that inhibits the enzyme in the dark, while dark inactivation occurs when RuBP binds to uncarbamylated sites.

61. (D) It utilizes ATP hydrolysis to alter Rubisco conformation, promoting the release of tightly bound sugar phosphates.
Rubisco often becomes inactive when sugar phosphates, such as its substrate RuBP or inhibitory analogs, bind tightly to its active sites. Rubisco activase is an AAA+ ATPase that utilizes the energy from ATP hydrolysis to induce conformational changes in Rubisco. This physical wrenching promotes the release of these tightly bound inhibitors, allowing the active site to be carbamylated and regain its catalytic competence.

62. (C) Formation of a carbamate on an epsilon-amino group of a specific lysine residue, followed by Mg^{2+} binding.
For Rubisco to become catalytically active, it must undergo a specific covalent modification. A molecule of carbon dioxide, distinct from the one used as a substrate, reacts with the epsilon-amino group of a conserved lysine residue to form a carbamate. This carbamate then coordinates with a magnesium ion. This complex stabilizes the active site architecture required for the subsequent carboxylation or oxygenation reactions.

63. (B) The specificity factor decreases, favoring oxygenase activity because CO_2 solubility decreases more than O_2 solubility.
The specificity factor of Rubisco measures its ability to discriminate between carbon dioxide and oxygen. As temperature increases, the solubility of carbon dioxide decreases more rapidly than that of oxygen. Furthermore, the kinetic properties of the enzyme shift to favor the oxygenase reaction. Consequently, at higher temperatures, the specificity factor decreases, leading to a higher rate of photorespiration relative to carbon fixation in C3 plants.

64. (D) Rubisco Assembly — Occurs exclusively in the cytosol.
Rubisco assembly is a complex process involving subunits from two different genomes. The large subunits are synthesized within the chloroplast, and the small subunits are imported from the cytosol. The final assembly of the eight-L-eight-S holoenzyme occurs within the chloroplast stroma, facilitated by specialized chaperonins. Stating that the assembly happens exclusively in the cytosol is incorrect, as it is a chloroplast-localized event.

65. (A) Increased O_2 competitively inhibits carboxylation, leading to enhanced synthesis of 2-phosphoglycolate.
Oxygen acts as a competitive inhibitor of the carboxylation reaction catalyzed by Rubisco. When atmospheric oxygen levels are high, especially under high light, Rubisco increasingly functions as an oxygenase. This reaction uses ribulose-one-five-bisphosphate and oxygen to produce one molecule of three-phosphoglycerate and one molecule of two-phosphoglycolate. The latter is a two-carbon compound that must be recycled through the energetically costly photorespiratory pathway.

66. (C) A nocturnal transition-state analog that binds tightly to the active site, inhibiting Rubisco activity in the dark.
CA1P, or two-carboxyarabinitol-one-phosphate, is a naturally occurring sugar phosphate found in many plant species. It acts as a potent nocturnal inhibitor of Rubisco by mimicking the transition state of the carboxylation reaction. CA1P binds tightly to the carbamylated active sites of Rubisco during the night, effectively shutting down carbon fixation when light is unavailable. It is removed by Rubisco activase following illumination.

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67. (A) Accumulation of CA1P.
In vivo activation of Rubisco in the light is promoted by several stromal changes. These include an increase in magnesium concentration, a shift to an alkaline pH, and the activity of Rubisco activase. The accumulation of CA1P, however, is an inhibitory process that occurs in the dark. In the light, CA1P is degraded or removed from the active sites, so its presence does not promote enzyme activation.

68. (D) Form II lacks the small subunits, functioning usually as a dimer of large subunits.
Form Two Rubisco is primarily found in certain photosynthetic bacteria and dinoflagellates. Unlike the Form One found in plants, which is composed of both large and small subunits, Form Two typically consists only of large subunits, often functioning as a dimer. It generally exhibits a lower specificity for carbon dioxide over oxygen and is thought to be more primitive in its structure compared to the holoenzyme.

69. (B) 3 ATP and 2 NADPH.
The assimilation of one molecule of carbon dioxide into the Calvin-Benson cycle requires specific amounts of energy and reducing power. Two molecules of ATP and two molecules of NADPH are consumed during the reduction of three-phosphoglycerate to glyceraldehyde-three-phosphate. An additional molecule of ATP is required in the regeneration phase to convert ribulose-five-phosphate into ribulose-one-five-bisphosphate. Thus, the total requirement is three ATP and two NADPH.

70. (A) I and II
The ferredoxin-thioredoxin system couples light reactions to the regulation of the Calvin cycle. In the light, electrons from Photosystem One reduce ferredoxin. Ferredoxin-thioredoxin reductase then transfers these electrons to thioredoxin, breaking its disulfide bond to form sulfhydryl groups. Reduced thioredoxin subsequently reduces the disulfide bonds of target enzymes, activating them. The statement that reduced thioredoxin oxidizes and inactivates these enzymes is incorrect.

71. (D) This phase directly releases the first CO_2 molecule of the cycle.
The reduction phase converts the three-carbon acid produced by Rubisco into a three-carbon sugar. This involves the phosphorylation of three-phosphoglycerate by phosphoglycerate kinase using ATP, followed by reduction by NADP-glyceraldehyde-three-phosphate dehydrogenase using NADPH. This phase does not release carbon dioxide; rather, it is the stage where the carbon captured from the atmosphere is energized for use in biosynthesis and sugar production.

72. (A) C3 + C3 → C6; C6 + C3 → C4 + C5.
The regeneration of ribulose-one-five-bisphosphate involves a complex series of sugar rearrangements. One common sequence begins with the condensation of two three-carbon triose phosphates to form a six-carbon fructose-one-six-bisphosphate. A transketolase then reacts a six-carbon ketose with a three-carbon aldose to yield a four-carbon and a five-carbon sugar. These pathways ensure that the acceptor molecules are replenished to maintain the cycle.

73. (B) Key cycle enzymes like FBPase and SBPase will remain in their oxidized, inactive state, stalling carbon fixation.
Ferredoxin-thioredoxin reductase is the central enzyme that links the redox state of the electron transport chain to the activation of several Calvin cycle enzymes. If this enzyme is inactive, key regulated enzymes such as fructose-one-six-bisphosphatase and sedoheptulose-one-seven-bisphosphatase will remain in their oxidized, inactive forms even in the light. This would prevent the regeneration of the carbon acceptor and stall the process.

74. (B) Transketolase — Transfers a two-carbon unit from a ketose to an aldose.
The Calvin-Benson cycle utilizes diverse enzymes to rearrange carbon skeletons. Transketolase is a key enzyme in the regeneration phase that transfers a two-carbon fragment from a ketose sugar to an aldose sugar. Other enzymes have different roles: phosphoribulokinase adds a phosphate to ribulose-five-phosphate, aldolase condenses triose phosphates, and epimerases or isomerases change the configuration of the sugar molecules without altering their carbon number.

75. (A) Phosphopentose isomerase.
Several steps in the Calvin-Benson cycle are highly exergonic and essentially irreversible, which helps drive the cycle in one direction. These include the reactions catalyzed by Rubisco, fructose-one-six-bisphosphatase, and sedoheptulose-one-seven-bisphosphatase. Phosphopentose isomerase, however, catalyzes a reversible interconversion between ribose-five-phosphate and ribulose-five-phosphate. This allows the system to reach equilibrium among the different five-carbon sugar phosphates produced during the regeneration phase.

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76. (C) The increase in stromal pH to ~8.0 provides the optimal alkaline environment for FBPase, promoting its activity.
During the light reactions, protons are pumped from the stroma into the thylakoid lumen. This results in an increase in the stromal pH, typically shifting from around seven to eight. Fructose-one-six-bisphosphatase is highly sensitive to these changes and has an alkaline pH optimum. The light-induced shift toward a more basic environment provides the ideal conditions for the enzyme to function, thereby activating carbon flow.

77. (D) Condense two three-carbon sugars (e.g., DHAP and GAP) to form a six-carbon sugar bisphosphate (e.g., FBP).
In the Calvin-Benson cycle, aldolase plays a critical role in increasing the carbon chain length of sugar intermediates. It catalyzes the reversible condensation of a three-carbon aldose, such as glyceraldehyde-three-phosphate, with a three-carbon ketose, such as dihydroxyacetone phosphate. This reaction produces a six-carbon sugar bisphosphate, which is then further processed in the cycle to eventually regenerate the five-carbon acceptor molecule.

78. (C) The production of both Erythrose-4-phosphate (C4) and Xylulose-5-phosphate (C5) will be immediately severely compromised.
Transketolase is responsible for several steps in the regeneration of ribulose-one-five-bisphosphate. It transfers two-carbon units to create four-carbon erythrose and five-carbon xylulose sugars from other intermediates. If transketolase activity is blocked, the plant cannot produce these essential precursors. This would lead to a severe deficit in the pool of five-carbon sugars required to sustain the cycle, effectively halting carbon fixation and metabolic throughput.

79. (B) A concentric arrangement of closely spaced mesophyll cells surrounding enlarged, chloroplast-rich bundle sheath cells.
Kranz anatomy is a specialized leaf structure found in most C4 plants. It is characterized by two distinct photosynthetic cell types: mesophyll cells and bundle sheath cells. The bundle sheath cells are large, thick-walled, and arranged in a ring-like fashion around the vascular bundles. These cells are surrounded by an outer layer of mesophyll cells, creating a concentric organization that facilitates the spatial separation of carbon fixation.

80. (B) I, II and III
C4 photosynthesis is classified into three main subtypes based on the primary enzyme used for the decarboxylation step in the bundle sheath cells. These are the NADP-malic enzyme subtype, the NAD-malic enzyme subtype, and the phosphoenolpyruvate carboxykinase subtype. The C2-oxidative cycle refers to photorespiration, which is not a C4 subtype but rather a process that C4 photosynthesis is designed to minimize or suppress.

81. (A) It utilizes PEP carboxylase to fix bicarbonate (HCO_3^-) into oxaloacetate in the cytosol of mesophyll cells.
In C4 plants, the initial capture of inorganic carbon occurs in the cytosol of mesophyll cells. The enzyme phosphoenolpyruvate carboxylase catalyzes the addition of bicarbonate to phosphoenolpyruvate. This reaction produces the four-carbon organic acid oxaloacetate. This strategy allows the plant to efficiently fix carbon even when stomata are partially closed, as PEP carboxylase has a high affinity for bicarbonate and does not react with oxygen.

82. (C) PEP carboxylase has a much higher affinity for its substrate (HCO_3^-), allowing efficient function at very low internal CO_2 concentrations.
Phosphoenolpyruvate carboxylase differs significantly from Rubisco in its kinetic properties. It uses bicarbonate as its substrate and exhibits a very high affinity for it, allowing the enzyme to function effectively even at low internal carbon dioxide concentrations. Furthermore, PEP carboxylase has no oxygenase activity, which prevents the competitive inhibition by oxygen that characterizes Rubisco and leads to the wasteful process of photorespiration in C3 plants.

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83. (A) C4 plants have higher WUE because the efficient PEP carboxylase allows them to maintain high photosynthetic rates with partially closed stomata.
Water use efficiency is the ratio of carbon gained to water lost via transpiration. C4 plants generally have higher WUE than C3 plants in hot and dry environments. The efficient initial fixation of carbon by PEP carboxylase allows C4 plants to maintain high rates of photosynthesis

even with reduced stomatal conductance. This minimizes water loss while preventing the increase in photorespiration observed in C3 plants.

84. (D) NADP-ME subtype — Pyruvate phosphate dikinase in the bundle sheath vacuole.
Each C4 subtype is defined by the location and identity of its decarboxylating enzyme. NADP-ME is in bundle sheath chloroplasts, NAD-ME is in bundle sheath mitochondria, and PCK is in the bundle sheath cytosol. Pyruvate phosphate dikinase is involved in regenerating the PEP acceptor in the mesophyll chloroplasts of all C4 plants. Stating it is located in the bundle sheath vacuole in the NADP-ME subtype is incorrect.

85. (B) Aspartate.
In the NADP-ME subtype of C4 photosynthesis, carbon is shuttled between cells using specific organic acids. Malate is synthesized in the mesophyll and transported to the bundle sheath for decarboxylation. The resulting pyruvate then returns to the mesophyll to regenerate PEP. While aspartate is a major transport metabolite in the NAD-ME and PCK subtypes, it is not the primary carrier used in the NADP-ME pathway.

86. (C) It significantly reduces the efflux (leakage) of CO_2 out of the bundle sheath, maintaining high CO_2 concentration around Rubisco.
Many C4 plants possess a layer of suberin in the cell walls of their bundle sheath cells. Suberin is a hydrophobic, waxy substance that significantly reduces the permeability of the cell wall to gases. This layer acts as a barrier that prevents the carbon dioxide released during decarboxylation from leaking back out into the mesophyll. This helps maintain the high internal CO_2 concentration necessary to saturate Rubisco.

87. (D) It suppresses photorespiration by concentrating CO_2 around Rubisco, which is advantageous in hot, arid, and high-light environments.
The C4 photosynthetic pathway evolved as a mechanism to concentrate carbon dioxide around the enzyme Rubisco. By spatially separating initial fixation and the Calvin cycle, C4 plants can effectively suppress photorespiration. This provides a major competitive advantage in environments characterized by high temperatures, high light intensity, and limited water availability, where C3 plants would otherwise lose a significant portion of their fixed carbon.

88. (A) The spatial separation of initial atmospheric carbon capture and final Rubisco-mediated fixation to elevate CO_2 at the active site of Rubisco.
The Carbon Concentrating Mechanism in C4 plants is a physiological strategy to increase the efficiency of Rubisco. It involves the spatial separation of the initial capture of atmospheric carbon dioxide, which occurs in mesophyll cells, and its final fixation in the bundle sheath cells. This two-step process effectively pumps CO_2 into the bundle sheath, elevating its concentration at the site of Rubisco and minimizing photorespiration.

89. (B) Exclusively during the dark period (night) when stomata are open (Phase I).
Crassulacean Acid Metabolism is characterized by a temporal separation of carbon fixation steps. During Phase One, which occurs at night, the plant opens its stomata and assimilates atmospheric carbon dioxide. This CO_2 is converted into bicarbonate and then fixed by PEP carboxylase into oxaloacetate, which is subsequently reduced to malate. This strategy allows the plant to acquire carbon when the evaporative demand is lowest.

90. (A) Both A and R are true and R is the correct explanation of A.
In CAM plants, the enzyme PEP carboxylase must be active at night to fix CO_2 and inactive during the day to prevent a futile cycle. This is achieved through reversible phosphorylation by a specific kinase. At night, the phosphorylated form is active and less sensitive to inhibition by malate. During the day, dephosphorylation renders the enzyme highly sensitive to malate inhibition, effectively shutting it down.

91. (A) Phase IV (Late Afternoon): Stomata remain strictly closed, completely relying on internal respiratory CO_2 until nightfall.
The four phases of CAM gas exchange describe metabolic activity over a twenty-four-hour cycle. Phase Four occurs in the late afternoon when internal malate stores are exhausted. If environmental conditions are favorable and the plant is not severely stressed, the stomata may open to allow direct C3-style carbon fixation by Rubisco. Therefore, stating that stomata remain

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strictly closed during this entire phase is an incorrect generalization.

92. (C) In the large central vacuole.
During the night, CAM plants synthesize large quantities of malic acid, which dissociates into malate and protons. To prevent the cytoplasm from becoming dangerously acidic, these products are actively transported into the large central vacuole of the mesophyll cells. The malic acid is stored there until the following day, when it is transported back into the cytoplasm and chloroplast for decarboxylation and subsequent fixation.

93. (D) PEPC would remain active during the day, creating a futile cycle competing with Rubisco for CO_2.
If a CAM plant had a mutation that caused its PEP carboxylase kinase to be active during the day, the PEP carboxylase enzyme would remain in its active, malate-insensitive state. As the plant attempts to fix the CO_2 released from malate decarboxylation using Rubisco, the active PEP carboxylase would compete for that same CO_2. This would create a futile metabolic cycle, wasting energy and reducing carbon efficiency.

94. (C) Phase III — Stomata closed, high internal CO_2 concentration, active Calvin cycle.
Each phase of CAM reflects a specific physiological state. Phase Three occurs during the midday and is characterized by closed stomata to prevent water loss. During this time, the malate stored in the vacuole is decarboxylated, creating a high internal concentration of carbon dioxide. This CO_2 is then fixed by the Calvin-Benson cycle using ATP and NADPH generated by light reactions, allowing photosynthesis to proceed.

95. (B) Thin, highly dissected leaves with exceptionally high stomatal densities.
Obligate CAM plants are adapted to arid environments and exhibit specific traits to maximize water use efficiency. These include high levels of succulence with large vacuoles for malate storage, thick cuticles, and reduced internal air spaces. They typically have low stomatal densities and thick, fleshy leaves rather than thin, highly dissected ones, as the latter would increase the surface area for evaporation and compromise drought-tolerance.

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96. (D) It triggers a transition from C3 photosynthesis to CAM metabolism to conserve water while maintaining some carbon gain.
Facultative CAM plants have the ability to switch their photosynthetic mode based on environmental conditions. When water is abundant, they often perform standard C3 photosynthesis. However, upon exposure to severe water deficit or high salinity, they trigger a transition to CAM metabolism. This shift allows the plant to close its stomata during the day and conserve water while continuing to gain carbon at night.

97. (A) C4 utilizes spatial separation (mesophyll vs bundle sheath) for decarboxylation, whereas CAM utilizes temporal separation (day vs night) within the same cell.
Both C4 and CAM photosynthesis use PEP carboxylase to concentrate CO_2 around Rubisco, but they differ in how they organize these steps. C4 plants use spatial separation, performing initial fixation in mesophyll cells and the Calvin cycle in bundle sheath cells. CAM plants use temporal separation, performing initial fixation at night and the Calvin cycle during the day, all within the same individual mesophyll cell.

98. (C) The chloroplast envelope membranes and chloroplast stroma.
Mesophyll conductance measures how easily carbon dioxide moves from the leaf's internal air spaces to the Rubisco enzyme in the chloroplast stroma. Several physical barriers contribute to this resistance, including the cell wall, the plasma membrane, the cytosol, and the double membrane of the chloroplast envelope. The transit through the liquid phase and various lipid bilayers represents a significant portion of the resistance to CO_2 diffusion.

99. (A) The phenomenon where plants preferentially utilize the lighter ${}^{\{12\}}CO_2$ isotope over the heavier ${}^{\{13\}}CO_2$ during diffusion and enzymatic fixation.
Carbon isotope discrimination is the preference of plants for the lighter isotope of carbon, carbon-twelve, over the heavier carbon-thirteen. This preference occurs during both the physical diffusion of carbon dioxide through the stomata and the chemical fixation by enzymes like Rubisco. Because molecules containing carbon-twelve move faster and react more readily, plant tissues naturally contain a lower ratio of carbon-thirteen to carbon-twelve.

100. (A) P-2, Q-1, R-3, S-4
Different photosynthetic pathways result in characteristic carbon isotope signatures. C3 plants show significant discrimination, with values around negative twenty-seven per mil. C4 plants, which use the efficient PEP carboxylase that discriminates less, have values around negative thirteen per mil. Obligate CAM plants often resemble C4 plants, while aquatic plants show high variability depending on whether they use dissolved CO_2 or bicarbonate.

101. (B) Plasma membrane H^+-ATPase activation hyperpolarizes the cell, driving K^+ and anion uptake to increase turgor.
Stomatal opening is an active process driven by changes in the turgor pressure of guard cells. Activation of plasma membrane H-ATPases pumps protons out of the cell, creating an electrochemical gradient that hyperpolarizes the membrane. This triggers the uptake of potassium ions and anions through specific channels. The resulting increase in solute concentration draws water into the guard cells via osmosis, causing opening.

102. (C) Phototropins.
Guard cells are highly sensitive to blue light, which serves as a signal for stomatal opening at the start of the day. This response is mediated by phototropins, which are blue-light-sensitive protein kinases. Upon activation by light, phototropins initiate a signaling cascade that leads to the activation of the plasma membrane H-ATPase. This pump provides the driving force for the ion uptake and turgor changes.

103. (D) Intercellular airspace resistance — Extremely high resistance due to tight cell packing in spongy mesophyll.
Carbon dioxide faces several resistances as it moves from the atmosphere to the chloroplast. These include the boundary layer resistance outside the leaf, stomatal resistance through the pores, and mesophyll resistance in the liquid phase. The resistance within the intercellular airspaces is generally considered to be very low because the rate of gaseous diffusion is much faster than diffusion through liquid in the leaf.

104. (A) Elevation of cytosolic free calcium ($Ca^{\{2+\}}$), which activates anion efflux channels and inhibits inward K^+ channels.
Abscisic acid is the primary hormone signaling drought stress and inducing stomatal closure. ABA triggers an increase in the concentration of free calcium ions in the guard cell cytosol. This elevated calcium activates anion efflux channels and inhibits inward-rectifying potassium channels. The resulting loss of solutes causes water to exit the cells, leading to a decrease in turgor and the closure of the pore.

105. (B) Increased thickening and suberization of mesophyll cell walls.
Mesophyll conductance is enhanced by structural features that reduce the distance or resistance carbon dioxide must overcome. These include thinner cell walls, larger chloroplast surface areas facing the air spaces, and the presence of specific aquaporins. Conversely, factors like increased cell wall thickening or the deposition of hydrophobic substances like suberin would increase the physical barrier to diffusion, thereby decreasing overall mesophyll conductance.

106. (B) It results in plant biomass being depleted in $^{\{13\}}C$ relative to atmospheric CO_2.
Rubisco has an inherent preference for carbon-twelve over carbon-thirteen during the carboxylation reaction. Because the enzyme reacts more slowly with carbon dioxide molecules containing the heavier isotope, the organic matter synthesized by the plant becomes depleted in carbon-thirteen compared to the atmospheric CO_2 supply. This isotopic fractionation provides a permanent signature in the plant's biomass reflecting its photosynthetic pathway.

107. (A) The crop likely suffered water stress, causing partial stomatal closure and forcing Rubisco to fix a higher proportion of the heavier $^{\{13\}}CO_2$ inside the leaf.
In C3 plants, the degree of carbon isotope discrimination is linked to stomatal conductance. When a plant is water-stressed, its stomata close partially, reducing the internal concentration of CO_2. As Rubisco consumes the available CO_2, it is forced to fix a greater proportion of the heavier carbon-thirteen isotope. This results in a less negative delta-thirteen-C value in the plant's dry matter.

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108. (C) Chloroplast, Peroxisome, and Mitochondrion.
The photorespiratory pathway, also known as the C2 oxidative photosynthetic carbon cycle, is a complex metabolic process that requires the cooperation of three different organelles. These are the chloroplast, the peroxisome, and the mitochondrion. Metabolites are shuttled between these compartments in a specific sequence to recover carbon from two-phosphoglycolate, which is produced when Rubisco reacts with oxygen instead of carbon dioxide.

109. (D) Glyoxylate is transported directly to the mitochondrion, where it is decarboxylated.
During photorespiration, glycolate produced in the chloroplast is sent to the peroxisome, where it is oxidized to glyoxylate and then converted to glycine. The glycine then moves to the mitochondrion to be decarboxylated and deaminated, forming serine. Serine subsequently returns to the peroxisome to be converted back into glycerate. The idea that glyoxylate is directly decarboxylated in the mitochondrion is incorrect; it must first become glycine.

110. (A) I and II
Ammonia is released in the mitochondria during the conversion of glycine to serine, a step catalyzed by the glycine decarboxylase complex. This nitrogen must be rapidly reassimilated to prevent toxicity and the loss of essential nutrients. However, this reassimilation does not occur in the mitochondria; it primarily takes place in the chloroplast stroma through the action of the glutamine synthetase and glutamate synthase enzymes.

111. (B) Hydroxypyruvate, which is then reduced to glycerate.
In the final recovery stages of the photorespiratory cycle, serine is transported from the mitochondrion back to the peroxisome. There, it undergoes an aminotransferase reaction to form hydroxypyruvate. This intermediate is then reduced to glycerate using NADH. The glycerate is finally transported back into the chloroplast, where it is phosphorylated to form three-phosphoglycerate, allowing the carbon to re-enter the Calvin-Benson cycle and minimize loss.

112. (D) Glycine decarboxylase complex (GDC) — Mitochondrion.
The enzymes of the photorespiratory pathway are localized in specific organelles. Glycolate oxidase and various aminotransferases are found in the peroxisome. Glycerate kinase is located in the chloroplast. The glycine decarboxylase complex, which catalyzes the conversion of glycine to serine while releasing carbon dioxide and ammonia, is strictly localized within the mitochondrial matrix, making it a definitive marker for this organelle.

113. (A) 2-Phosphoglycolate.
During photorespiration, the peroxisome receives several metabolites from other compartments, including glycolate from the chloroplast and serine from the mitochondrion. Glutamate also enters the peroxisome to act as an amino donor. However, two-phosphoglycolate is the initial product formed by Rubisco in the chloroplast; it is dephosphorylated to glycolate before being exported, so the phosphorylated form itself does not enter the peroxisome.

114. (C) It consumes ATP and reducing equivalents to salvage carbon while releasing previously fixed CO_2.
Photorespiration is considered energetically expensive because it consumes ATP and reducing equivalents while simultaneously releasing carbon dioxide that had already been fixed. The process is necessary to salvage the carbon from two-phosphoglycolate, which would otherwise be lost. However, the energy required to recycle this carbon and reassimilate the ammonia produced is significant, reducing the overall net efficiency of photosynthesis in C3 plants.

115. (A) To bypass the mitochondrion, thereby concentrating CO_2 directly within the chloroplast, reducing energy waste and increasing photosynthetic yield.
Scientists have engineered synthetic photorespiratory bypasses to improve crop productivity. These pathways aim to break down glycolate entirely within the chloroplast rather than shuttling it through the peroxisome and mitochondrion. By doing so, carbon dioxide is released directly at the site of Rubisco, which can then be refixed more efficiently. This reduces the energy lost during transport and ammonia reassimilation.

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116. (D) 3-PGA can immediately enter the Calvin cycle for reduction, whereas 2-phosphoglycolate must be salvaged via a complex multi-organelle pathway.
Rubisco produces two different molecules depending on whether it uses CO_2 or O_2 as a substrate. Carboxylation yields two molecules of three-phosphoglycerate, which can directly enter the reduction phase of the Calvin cycle. Oxygenation produces one molecule of three-phosphoglycerate and one molecule of two-phosphoglycolate. Unlike the former, the two-carbon phosphoglycolate cannot be used directly and must undergo the extensive photorespiratory salvage pathway.

117. (B) It protects the photosynthetic apparatus from photooxidative damage under high-light and low CO_2 conditions by maintaining electron flow.
Although photorespiration is energy-intensive, it serves an important photoprotective function. Under conditions of high light and low CO_2 availability, such as when stomata are closed during drought, the Calvin cycle slows down. Photorespiration provides an alternative sink for ATP and reducing power, which maintains the flow of electrons through the transport chain. This prevents the over-reduction of carriers and helps protect the photosynthetic apparatus.

118. (C) ADP-glucose pyrophosphorylase (AGPase).
The synthesis of starch in the chloroplast begins with the conversion of glucose-one-phosphate and ATP into ADP-glucose. This reaction is catalyzed by the enzyme ADP-glucose pyrophosphorylase. This step is the first committed and most highly regulated stage of the pathway. Its activity is controlled by the ratio of three-phosphoglycerate to inorganic phosphate, ensuring that starch synthesis is coordinated with carbon availability.

119. (D) SPS is allosterically activated by Glucose-6-phosphate and inhibited by inorganic phosphate (Pi).
Sucrose-phosphate synthase is a key enzyme in the cytosolic pathway for sucrose synthesis. Its activity is allosterically regulated to coordinate with the metabolic state of the cell. Specifically, it is activated by glucose-six-phosphate, which signals an abundance of hexose precursors. Conversely, it is inhibited by inorganic phosphate, which indicates that phosphate is being depleted from the stroma or that fixation is low.

120. (B) II and III
The breakdown of transitory starch at night involves several enzymes. Beta-amylase is responsible for cleaving maltose units from the ends of the glucan chains, and it is the primary enzyme for releasing this sugar for export. Isoamylase is a debranching enzyme that hydrolyzes the alpha-one-six glycosidic bonds, allowing the amylases to access more of the starch polymer. Together, they convert starch into sugars.

121. (B) It acts as a potent regulatory signal molecule in the cytosol, inhibiting cytosolic FBPase and activating PPi-PFK, thereby shifting flux toward glycolysis rather than sucrose synthesis.
Fructose-two-six-bisphosphate is a powerful regulatory signal molecule found in the cytosol of plant cells. It is not a metabolic intermediate but rather controls the flux between sucrose synthesis and glycolysis. By inhibiting the cytosolic fructose-one-six-bisphosphatase and activating the pyrophosphate-dependent phosphofructokinase, it prevents the synthesis of sucrose and promotes the breakdown of hexoses for energy production or other biosynthetic needs.

122. (B) ADP-glucose pyrophosphorylase (AGPase) — Vacuole.
The enzymes of carbohydrate metabolism are located in specific subcellular compartments. Starch synthase and ADP-glucose pyrophosphorylase are localized in the plastids, where starch is synthesized and stored. Sucrose synthase is found in the cytosol. Stating that ADP-glucose pyrophosphorylase is located in the vacuole is incorrect, as this enzyme is essential for plastidic starch formation and does not function within the acidic vacuole.

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123. (A) Starch synthesis continues at its maximal rate throughout the dark period.
Transitory starch exhibits a rhythmic pattern of synthesis and degradation over a twenty-four-hour cycle. During the day, it accumulates as a product of photosynthesis. At night, it is degraded to provide a constant supply of carbon for respiration and phloem export. This degradation is carefully regulated to ensure that the starch stores last until dawn, meaning it does not continue at its maximal rate.

124. (C) Triose phosphates accumulate in the stroma, leading to starch overproduction while cytosolic sucrose synthesis is starved.
The Triose Phosphate Translocator mediates the exchange of triose phosphates for inorganic phosphate across the chloroplast envelope. If this translocator is blocked, triose phosphates produced by the Calvin cycle cannot be exported to the cytosol for sucrose synthesis. This causes them to accumulate in the chloroplast stroma, where they are instead converted into starch. Consequently, the plant overproduces starch while the cell is starved.

125. (D) Granular starch synthesized in the chloroplast during the day and degraded the following night to sustain metabolism.
Transitory starch refers to the starch that is synthesized within the chloroplasts of leaf mesophyll cells during the day. It serves as a temporary reservoir of fixed carbon that is mobilized during the following night. This process ensures that the plant has a continuous supply of energy and carbon skeletons for growth and maintenance, even when the light reactions of photosynthesis are not active.

126. (C) Amylose is synthesized primarily by Granule-Bound Starch Synthase (GBSS), whereas amylopectin relies on Soluble Starch Synthases (SS) and Branching Enzymes (SBE).
Starch granules are composed of two polymers: amylose and amylopectin. Amylose is primarily linear and is synthesized by Granule-Bound Starch Synthase. In contrast, amylopectin is a highly branched polymer produced through the coordinated action of multiple isoforms of soluble starch synthases and starch branching enzymes. These branching enzymes introduce the alpha-one-six linkages that give amylopectin its complex structure, which accounts for starch majority.

127. (B) A mass flow of sap driven by an osmotically generated positive hydrostatic pressure gradient between source and sink regions.
The Münch hypothesis explains phloem transport as a mass flow process. Active loading of sugars into the sieve elements at the source creates a low osmotic potential, drawing water in and increasing hydrostatic pressure. Conversely, the unloading of sugars at the sink causes water to leave, lowering the pressure. This resulting pressure gradient between source and sink regions drives the bulk flow of phloem sap.

128. (D) It relies entirely on secondary active transporters (H^+/symporters) in the plasma membrane of the sieve element.
The polymer trapping model is a mechanism for symplastic phloem loading. Sucrose diffuses through plasmodesmata into intermediary cells, where it is used to synthesize larger oligosaccharides like raffinose. These larger molecules cannot diffuse back because the plasmodesmata are too narrow. This creates a high concentration of sugars in the phloem without the need for plasma membrane-localized transporters characteristic of the alternative apoplastic loading mechanism.

129. (A) The reliance on plasma membrane-localized sucrose-proton symporters (e.g., SUT1/SUC2) to actively load sucrose from the cell wall space.
Apoplastic loading involves the movement of sucrose from the mesophyll into the cell wall space, followed by active uptake into the sieve element-companion cell complex. This uptake is mediated by specific sucrose-proton symporters, such as SUC2 or SUT1, which utilize the proton gradient generated by H-ATPases. This mechanism is distinct from symplastic loading, which relies on the continuous movement of sugars through plasmodesmata.

130. (A) Both A and R are true and R is the correct explanation of A.
In plants that utilize apoplastic loading, the uptake of sucrose into the phloem is an active process coupled to the movement of protons. A plasma membrane H-ATPase creates a proton motive force that drives sucrose/H^+ symporters. Treating source leaves with a protonophore dissipates this proton gradient, removing the energy source for the transporters. This results in the cessation of phloem loading, demonstrating gradient requirement.

131. (A) Raffinose and Stachyose — Polymer trapping (symplastic loading).
Different plants use specific mechanisms to load various sugars into the phloem. Species that transport raffinose-family oligosaccharides typically utilize the symplastic polymer trapping model, where the size of the sugars prevents their return to the mesophyll. On the other hand, plants that primarily transport sucrose often

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use apoplastic loading, where sucrose is actively taken up from the cell wall space by specialized protein transporters.

132. (D) Complex, undigested polysaccharides like cellulose and pectin.
Phloem sap is a complex and concentrated solution containing sugars, amino acids, various ions, and signaling molecules. It is enriched in potassium and contains diverse proteins and RNAs involved in long-distance communication. However, it does not typically contain large, insoluble structural polysaccharides like cellulose and pectin. These molecules are components of the cell wall and are far too large for phloem transport.

133. (B) The aphid stylet precisely penetrates a single sieve tube element without triggering the massive callose and P-protein sealing response, providing pure exudate.
The aphid stylet technique is a powerful tool for studying phloem because aphids naturally feed on the sap. The insect precisely inserts its stylet into a single sieve tube element. By using a laser to sever the stylet from the aphid, researchers can collect the sap as it exudes under natural pressure. This method avoids the wounding responses, such as callose deposition, that occur mechanically.

134. (C) It ensures that there is no direct symplastic continuity between maternal tissues and the developing embryo, allowing independent genetic and osmotic regulation.
In many developing seeds, there is no symplastic connection between the maternal tissues and the embryo. This necessitates an apoplastic unloading step, where nutrients are released into the seed coat and then taken up by the embryo. This lack of continuity is crucial because it prevents pathogen movement between generations and allows the seed to maintain an independent genetic and osmotic environment during development.

135. (D) Damage-response mechanisms that rapidly form plugs at sieve plates to prevent the catastrophic loss of high-pressure phloem sap upon injury.
The phloem is under high hydrostatic pressure, making it vulnerable to catastrophic sap loss if damaged. Angiosperms have evolved two main mechanisms to prevent this: the accumulation of P-proteins and the rapid synthesis of callose. Upon injury, P-proteins aggregate to form plugs in the sieve pores, and callose is deposited over the sieve plates. These actions seal the damaged sieve tubes, preserving integrity.

136. (A) Intermediary cells possess numerous plasmodesmata connections for symplastic loading, whereas transfer cells have cell wall ingrowths adapted for high-capacity apoplastic loading.
Companion cells are specialized according to the type of phloem loading they perform. Intermediary cells are characterized by numerous large, branched plasmodesmata that facilitate the symplastic movement of sugars. In contrast, transfer cells have extensive inward foldings of the plasma membrane and cell wall. These ingrowths significantly increase the surface area available for the numerous transporters required for high-capacity apoplastic loading.

137. (B) Any organ that relies on the import of photoassimilates to support its growth or storage needs.
In the context of plant physiology, a sink tissue is any organ or part of the plant that is a net importer of photoassimilates. These tissues depend on the supply of sugars and other nutrients from source leaves to support their metabolic activities, which may include rapid growth, cellular respiration, or the accumulation of storage reserves like starch and protein in seeds or roots.

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138. (B) Developing seeds/fruits become the dominant sinks, often drawing assimilates heavily from nearby source leaves and sometimes mobilizing reserves from stems.
During the reproductive phase, the primary goal of the plant is to ensure the development of seeds and fruits. These organs become the most powerful sinks, effectively competing for the available assimilates produced by the source leaves. In some cases, the demand is so high that the plant will mobilize stored reserves from vegetative tissues like stems and older leaves to support requirements.

139. (A) Sink size multiplied by sink activity (the specific rate of uptake and utilization of assimilates).
Sink strength is the competitive ability of a sink organ to attract assimilates from the phloem.

It is mathematically defined as the product of two factors: sink size and sink activity. Sink size refers to the total physical biomass of the organ, while sink activity is the rate at which the tissue takes up and utilizes imported sugars. Both factors determine the overall demand.

140. (A) P-1, Q-4, R-2, S-3
Several enzymes regulate the flow and use of sucrose in sink tissues. Cell wall invertase hydrolyzes sucrose in the apoplast to maintain a concentration gradient for unloading. Vacuolar invertase regulates internal sucrose levels for osmotic control and expansion. Sucrose synthase cleaves sucrose for starch or cellulose synthesis, while ADP-glucose pyrophosphorylase catalyzes the first committed step of starch production within the amyloplasts.

141. (D) Senescing leaf — Reverts back to being a strong sink to import nutrients before death.
As a leaf develops, it undergoes a transition from a net importer to a net exporter of nutrients. Young, expanding leaves are sinks, while mature, fully expanded leaves are sources. During the transition, both loading and unloading can occur simultaneously in different parts of the leaf. However, senescing leaves do not revert to being sinks; they instead remobilize their own nutrients and export them.

142. (C) Drastically increasing the height and biomass of the vegetative stem (lodging susceptible).
Harvest index is the ratio of grain yield to total above-ground biomass. Strategies to improve it include enhancing phloem loading, increasing the grain-filling duration, and upregulating enzymes in the seeds. Conversely, increasing the biomass of the vegetative stem would decrease the harvest index, as it allocates more energy to non-harvested tissues. Furthermore, very tall stems are prone to lodging.

143. (B) By the rapid and active uptake of sucrose (or its hexose cleavage products) by specific transporters on the cotyledon (embryo) epidermal cells.
In legume seeds, sucrose is unloaded into the apoplastic space between the seed coat and the embryo. To maintain a steep concentration gradient that drives further efflux from the maternal tissues, the embryo must rapidly remove the sucrose from the apoplast. This is achieved through the active uptake of sucrose or its cleavage products by high-affinity transporters located on the embryo epidermal cells.

144. (D) Introduction of dwarfing genes (e.g., Rht in wheat) reduced stem biomass, thereby dramatically increasing the proportion of assimilates partitioned to the grain (higher harvest index).
A key breakthrough of the Green Revolution was the development of semi-dwarf varieties of wheat and rice. These plants carried mutations in genes like Rht, which reduced their overall height and stem biomass. By minimizing the energy spent on growing tall stems, the plants were able to allocate a much larger proportion of photoassimilates to the grain, increasing the harvest index.

145. (A) Hexoses generated by cell wall invertase often promote cell division and expansion, delaying differentiation and starch storage until the sink size is established.
Hexose sugars like glucose and fructose play a vital signaling role during early seed development. High concentrations of these sugars, often generated by the activity of cell wall invertases, promote cell division and expansion in the young embryo. This ensures that the sink organ reaches its full size before the plant transitions into the later stages of development involving storage compound accumulation.

146. (C) 2 ATP and 2 NADH.
The cytosolic pathway of glycolysis involves the breakdown of one molecule of glucose into two molecules of pyruvate. This process requires an initial investment of two ATP molecules but subsequently generates four ATP molecules through substrate-level phosphorylation. Additionally, two molecules of NAD+ are reduced to NADH. Therefore, the net energy yield for the entire pathway is two ATP and two NADH.

147. (A) PPi-PFK catalyzes a highly irreversible step, forcing glycolysis strongly forward regardless of energy status.
Plants possess unique glycolytic enzymes that provide metabolic flexibility. One example is the pyrophosphate-dependent phosphofructokinase, which uses PPi instead of ATP. This enzyme catalyzes a reversible reaction, unlike the highly irreversible ATP-dependent PFK. This reversibility allows the plant to adjust carbon

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flux according to the availability of phosphate and energy, which is particularly beneficial under conditions like energy-depleting anoxia.

148. (D) Pyruvate decarboxylase and Alcohol dehydrogenase.
When plant roots are deprived of oxygen, they shift from oxidative phosphorylation to fermentation to regenerate NAD+ and maintain glycolysis. For ethanol fermentation, pyruvate is first converted into acetaldehyde by the enzyme pyruvate decarboxylase, releasing carbon dioxide in the process. Acetaldehyde is then reduced to ethanol by alcohol dehydrogenase, which uses the electrons from NADH produced during the earlier stages of glycolysis.

149. (B) Pyruvate kinase — Inhibited by ATP.
The flux through glycolysis is tightly controlled by the allosteric regulation of its key enzymes. Pyruvate kinase, which catalyzes the final step of the pathway, is strongly inhibited by high levels of ATP. This feedback mechanism ensures that the rate of glucose breakdown decreases when the cell has an abundant energy supply, preventing the unnecessary consumption of carbon when metabolic demand is low.

150. (B) I, II and III
Plants utilize several enzymes that provide alternative routes in carbon metabolism. PPi-dependent phosphofructokinase and non-phosphorylating NADP-GAPDH offer flexibility in the glycolytic pathway. Phosphoenolpyruvate carboxylase is important for the formation of organic acids like malate, which can then enter the mitochondria. Rubisco, however, is the primary enzyme for carbon fixation in the chloroplast and does not participate in cytosolic glycolysis.

151. (D) The interconversion of dihydroxyacetone phosphate and glyceraldehyde-3-phosphate by triose phosphate isomerase.
Glycolysis contains several steps with large negative free energy changes that are considered irreversible in the cell, such as those catalyzed by hexokinase, ATP-dependent PFK, and pyruvate kinase. These steps serve as major regulatory points. In contrast, the interconversion of dihydroxyacetone phosphate and glyceraldehyde-three-phosphate by triose phosphate isomerase is a reversible reaction that reaches equilibrium quickly, allowing interchangeability.

152. (A) Acceleration of glycolytic flux to compensate for the lower ATP yield of fermentation compared to oxidative phosphorylation.
The Pasteur effect is a common response to anoxia or hypoxia in many organisms. When oxidative phosphorylation is inhibited due to a lack of oxygen, the yield of ATP per glucose molecule drops significantly. To maintain the energy required for cellular survival, the plant dramatically accelerates the rate of glycolysis and fermentation. This increased glucose consumption helps compensate for anaerobic inefficiency.

153. (B) Initial anoxia triggers lactate fermentation, causing cytosolic pH to drop; this acidification inhibits lactate dehydrogenase and activates pyruvate decarboxylase, shifting flux to ethanol production.
Upon sudden anoxia, plant roots initially perform lactic acid fermentation. As lactate accumulates, the cytosolic pH begins to drop. This acidification inhibits lactate dehydrogenase and simultaneously activates pyruvate decarboxylase. This metabolic switch shifts the carbon flux from lactate to ethanol production. This is beneficial because ethanol and the carbon dioxide produced can diffuse out of the root more easily.

154. (B) The direct transfer of a high-energy phosphate group from a metabolic intermediate (e.g., 1,3-bisphosphoglycerate) to ADP to form ATP.
Substrate-level phosphorylation is a method of ATP synthesis that does not involve an electrochemical gradient or ATP synthase. It occurs when a high-energy phosphate group is transferred directly from a metabolic intermediate to an ADP molecule. In glycolysis, this happens during the reactions catalyzed by phosphoglycerate kinase and pyruvate kinase, where energy released from breakdown is captured as ATP.

155. (A) Isozymes for glycolytic steps exist in both compartments, but plastidic glycolysis primarily provides carbon skeletons (e.g., for lipid synthesis) rather than serving as the main energy-yielding pathway for the whole cell.
Most plant cells contain complete sets of glycolytic enzymes in both the cytosol and the plastids. While cytosolic glycolysis is the primary pathway for generating energy for the

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whole cell, plastidic glycolysis plays a specialized role. It primarily functions to provide carbon skeletons and reducing power for biosynthetic processes occurring within the plastid, such as the synthesis of fatty acids.

156. (C) Cristae; to drastically increase the surface area available for housing electron transport chain complexes and ATP synthase.
The inner membrane of a plant mitochondrion is highly folded into structures known as cristae. These invaginations are essential because they drastically increase the surface area available for the various components of the respiratory system. The cristae house the protein complexes of the electron transport chain and the ATP synthase molecules, allowing for a much higher density of oxidative phosphorylation.

157. (D) It allows plant mitochondria to oxidize malate directly to pyruvate and CO_2, bypassing the requirement for cytosolic pyruvate entry.
Plant mitochondria contain a specific isoform of malic enzyme that uses NAD+ as a cofactor. This enzyme catalyzes the oxidative decarboxylation of malate to form pyruvate and carbon dioxide. This is a unique feature of plant metabolism that allows the mitochondria to oxidize malate directly. This provides a bypass that reduces the dependence on the import of pyruvate.

158. (C) 4 NADH, 1 FADH2, and 1 ATP (or GTP).
The oxidation of one molecule of pyruvate begins with its conversion to acetyl-CoA, which produces one NADH. In the subsequent turn of the TCA cycle, three more molecules of NADH, one molecule of FADH2, and one molecule of ATP (or GTP) are generated. Therefore, the complete oxidation of a single pyruvate molecule through the combined action of PDC and TCA yields four NADH.

159. (B) Succinate dehydrogenase — Substrate-level phosphorylation.
The enzymes of the TCA cycle perform specific chemical transformations. Citrate synthase catalyzes a condensation, while isocitrate dehydrogenase performs an oxidative decarboxylation. Succinate dehydrogenase is an enzyme that oxidizes succinate to fumarate while reducing FAD to FADH2. The substrate-level phosphorylation step in the cycle is actually catalyzed by succinyl-CoA synthetase, which produces ATP or GTP while converting succinyl-CoA into succinate.

160. (A) Citrate $\rightarrow$ Isocitrate $\rightarrow$ α-Ketoglutarate $\rightarrow$ Succinyl-CoA.
The TCA cycle begins when acetyl-CoA condenses with oxaloacetate to form citrate. This molecule is then isomerized into isocitrate. The cycle proceeds with two successive oxidative decarboxylation reactions, which first produce alpha-ketoglutarate and then succinyl-CoA. Each of these steps releases a molecule of carbon dioxide and generates NADH, moving the carbon atoms through the first half of the respiratory cycle.

161. (A) Cytochrome c oxidase.
Anaplerotic reactions are essential for replenishing the intermediates of the TCA cycle that are withdrawn for biosynthetic purposes. Enzymes like PEP carboxylase and malate dehydrogenase help maintain the pool of four-carbon acids. In contrast, cytochrome c oxidase is the terminal enzyme of the mitochondrial electron transport chain. Its role is strictly to transfer electrons to molecular oxygen to form water.

162. (C) It bypasses the α-ketoglutarate dehydrogenase step of the TCA cycle, converting glutamate to GABA, which is subsequently converted to succinate.
The GABA shunt is a metabolic pathway that provides an alternative route into the TCA cycle. It involves the conversion of glutamate into gamma-aminobutyric acid, which is then metabolized into succinate. This bypasses the alpha-ketoglutarate dehydrogenase complex, which can be sensitive to inhibition. This shunt is particularly important in plants under stress, as it helps maintain carbon flow through the cycle.

163. (A) It leads to the synthesis of glutamic acid, while necessitating heightened anaplerotic carbon flow (via PEPC) to replenish cycle intermediates.
The TCA cycle is amphibolic, functioning in both catabolism and anabolism. During active nitrogen assimilation, large amounts of alpha-ketoglutarate are withdrawn from the cycle to synthesize glutamate. This withdrawal would deplete the cycle's intermediates if not for anaplerotic reactions. The plant uses enzymes

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like PEP carboxylase to fix CO_2 and produce more oxaloacetate, which replenishes the cycle.

164. (D) Catalyzes the oxidative decarboxylation of pyruvate to acetyl-CoA, simultaneously reducing NAD+ to NADH.
The pyruvate dehydrogenase complex is a massive multi-enzyme assembly located in the mitochondrial matrix. It serves as the bridge between glycolysis in the cytosol and the TCA cycle in the mitochondria. The complex catalyzes the oxidative decarboxylation of pyruvate. This reaction removes a carbon atom as CO_2 and attaches the remaining two-carbon acetyl group to coenzyme A while reducing NAD+.

165. (A) Succinyl-CoA synthetase → Succinate dehydrogenase → Fumarase → Malate dehydrogenase.
The latter half of the TCA cycle involves the conversion of succinyl-CoA back into oxaloacetate. The sequence begins with succinyl-CoA synthetase, which generates ATP while producing succinate. Succinate is then oxidized by succinate dehydrogenase to form fumarate. Fumarate is hydrated by fumarase to produce malate, and finally, malate is oxidized by malate dehydrogenase to regenerate oxaloacetate, completing the respiratory cycle.

166. (C) It transfers electrons from succinate to ubiquinone without pumping any protons across the inner membrane.
Complex Two, also known as succinate dehydrogenase, is unique because it is the only enzyme that participates in both the TCA cycle and the mitochondrial electron transport chain. It oxidizes succinate to fumarate while reducing FAD to FADH2. The electrons are then transferred directly to the ubiquinone pool. Unlike other complexes, it does not pump any protons across the inner membrane.

167. (D) The transfer of electrons through these alternative dehydrogenases is highly coupled to proton pumping, generating maximum ATP.
Plant mitochondria contain alternative NAD(P) H dehydrogenases that are not found in animal cells. These enzymes allow for the oxidation of both matrix and cytosolic NADH and are resistant to the inhibitor rotenone. However, these alternative pathways are not coupled to proton pumping. Consequently, while they allow electron transport to continue, they result in a significantly lower yield of ATP than standard pathways.

168. (A) Approximately 2.5.
The P/O ratio represents the number of ATP molecules synthesized per oxygen atom reduced by a pair of electrons. Modern measurements take into account the proton stoichiometry of the respiratory complexes and the ATP synthase. For the oxidation of a single molecule of matrix NADH through the full cytochrome pathway, approximately ten protons are pumped, resulting in an estimated ratio of two point five.

169. (B) Cyanide (CN-) — Strongly binds to and inhibits the binuclear center of Complex IV.
Various chemicals can specifically block different parts of the mitochondrial respiratory chain. Rotenone inhibits Complex One, and antimycin A blocks Complex Three. Cyanide is a potent poison that binds strongly to the iron and copper atoms in the binuclear center of cytochrome c oxidase, which is Complex Four. This prevents the final transfer of electrons to oxygen, halting oxidative phosphorylation.

170. (A) Both A and R are true and R is the correct explanation of A.
The synthesis of ATP in mitochondria is driven by the movement of protons through the ATP synthase complex. This complex consists of a membrane-embedded Fo part and a catalytic F1 part. As protons flow through the Fo channel, they drive the physical rotation of the central gamma-subunit. This rotation induces sequential conformational changes in the F1 head, driving the condensation of ADP.

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171. (A) Plastoquinone.
The mitochondrial electron transport chain uses small molecules to shuttle electrons between the large protein complexes. Ubiquinone moves electrons within the lipid bilayer, while cytochrome c is a small protein that moves along the surface of the inner membrane. Cytochrome c1 is a stationary part of Complex Three. Plastoquinone is also a mobile electron carrier, but it is found in chloroplasts.

172. (C) By facilitating the re-entry of protons from the intermembrane space back into the matrix,

bypassing the ATP synthase and dissipating the gradient as heat.
Uncoupling proteins are specialized transport proteins located in the inner mitochondrial membrane. Their primary function is to facilitate the regulated return of protons from the intermembrane space back into the matrix. By providing an alternative route for protons that bypasses the ATP synthase, these proteins dissipate the electrochemical gradient as heat, reducing the efficiency of ATP synthesis and managing energy.

173. (D) The membrane potential ($\Delta\psi$) makes the largest quantitative contribution to the total driving force.
The proton motive force is the total potential energy available from the electrochemical proton gradient. In plant mitochondria, this force is dominated by the membrane potential, which represents the electrical charge difference across the inner membrane. While the pH gradient also contributes to the driving force, it is generally smaller in magnitude than the membrane potential, providing the energy for synthesis.

174. (C) Routes electrons from ubiquinol to cytochrome c while effectively doubling the number of protons pumped across the membrane per electron pair.
The Q-cycle is a specialized mechanism within the cytochrome bc1 complex that maximizes the efficiency of proton pumping. As ubiquinol is oxidized, the cycle allows for the bifurcated transfer of electrons, which leads to the translocation of more protons than a simple linear transfer would allow. Specifically, for every pair of electrons, four protons are moved, effectively doubling the energetic contribution.

175. (B) The chloroplast ATP synthase is uniquely regulated by light/dark transitions via a built-in redox-sensitive thioredoxin regulatory switch on its γ-subunit, which is largely absent in mitochondria.
While both ATP synthases are structurally similar, they differ in their regulation. The chloroplast version, CF1CFo, has a unique redox-sensitive switch on its gamma-subunit. This allows the enzyme to be activated by thioredoxin in the light and inactivated in the dark, preventing wasteful hydrolysis. Plant mitochondrial ATP synthases generally lack this specific light-dependent regulatory mechanism as they function continuously.

176. (D) At the Ubiquinone (UQ) pool.
The alternative oxidase pathway provides a parallel route for electrons in the mitochondrial respiratory chain. This pathway branches off at the level of the ubiquinone pool. Instead of electrons passing from ubiquinone to Complex Three and then to Complex Four, they are transferred directly from ubiquinol to the alternative oxidase enzyme. From there, the electrons reduce molecular oxygen to water.

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177. (A) Electron flow from ubiquinol to oxygen via AOX bypasses proton-pumping Complexes III and IV, significantly reducing the ATP yield per NADH oxidized.
The alternative oxidase pathway is much less efficient at generating ATP than the cytochrome pathway. Because it branches off at ubiquinone, the electrons bypass the proton-pumping steps of Complexes Three and Four. Only the protons pumped by Complex One are conserved in this pathway. Consequently, most of the energy released from the oxidation of substrates is lost as heat.

178. (C) Salicylhydroxamic acid (SHAM).
In experimental studies of plant respiration, specific inhibitors are used to distinguish between different pathways. Cyanide is used to block the cytochrome pathway. To selectively inhibit the alternative oxidase, researchers typically use salicylhydroxamic acid, commonly known as SHAM. These inhibitors bind to the active site of the AOX enzyme, allowing scientists to measure the contribution of this alternative pathway.

179. (A) Primary carbon source — Direct and exclusive assimilation of atmospheric CO_2 in the dark.
Intense thermogenesis occurs in the flowers of some plants, such as Arum lilies, and is driven by the alternative oxidase pathway. This process consumes massive amounts of stored carbohydrates, such as starch, to produce heat. The heat volatilizes foul-smelling compounds that attract pollinators. This activity is powered by the rapid breakdown of previously stored internal carbon reserves, not direct assimilation.

180. (A) P-3, Q-4, R-1, S-2
Plant mitochondria feature several unique respiratory systems. The alternative oxidase reduces oxygen to water while releasing heat. Uncoupling proteins dissipate the proton gradient to reduce ATP synthesis efficiency. External NAD(P)H dehydrogenases oxidize cytosolic NADH without pumping protons, while rotenone-insensitive internal dehydrogenases do the same for matrix NADH. These systems collectively provide plants with significant metabolic flexibility for stress response.

181. (B) Maximizing the strict maximum yield of ATP per molecule of glucose oxidized.
In non-thermogenic tissues, the alternative oxidase pathway plays several protective roles. It helps prevent the over-reduction of the ubiquinone pool and limits the formation of reactive oxygen species. It also allows the TCA cycle to continue producing carbon skeletons even when ATP demand is satisfied. However, because it bypasses major proton-pumping complexes, it does not maximize the ATP yield.

182. (C) Highly reduced ubiquinone pool, high matrix pyruvate, and reduced AOX (free sulfhydryl groups).
The activity of the alternative oxidase is tightly controlled by the metabolic state of the mitochondria. The enzyme exists as a dimer that is most active in its reduced state, with free sulfhydryl groups. Furthermore, AOX is allosterically activated by organic acids, particularly pyruvate. Its activity increases when the ubiquinone pool is highly reduced, ensuring activation during chain saturation.

183. (D) Stress factors induce strong transcriptional upregulation and increased capacity of the AOX pathway to maintain metabolic flexibility and limit oxidative damage.
Plants often upregulate the alternative oxidase pathway when subjected to environmental stresses like chilling, drought, or nutrient starvation. These conditions can disrupt the standard respiratory chain or lead to the accumulation of reactive oxygen species. By increasing the capacity of the AOX pathway through transcriptional upregulation, the plant can maintain essential metabolic processes and protect the mitochondria from oxidative damage.

184. (A) It demonstrates the presence of a parallel, non-phosphorylating terminal oxidase (AOX) that ensures electron transport can continue even if the primary cytochrome pathway is compromised.
The observation that plant respiration can continue even in the presence of cyanide led to the discovery of the alternative oxidase. This enzyme provides a terminal oxidase that is resistant to cyanide inhibition. The existence of this parallel pathway demonstrates that plants have evolved redundant systems to ensure that electron transport can persist even if the primary cytochrome pathway is blocked.

185. (B) It is the energy expended to preserve existing biomass, including protein turnover, maintaining ion gradients, and cellular repair.
Total dark respiration is composed of two functional parts. Maintenance respiration represents the energy used to preserve the existing structure and function of the plant. This includes the energy required for the continuous turnover of proteins, the maintenance of ion concentrations across membranes, and various cellular repair mechanisms. It is essential for the survival of already established tissues and existing biomass.

186. (B) The specific rate of maintenance respiration is entirely independent of environmental temperature.
Maintenance respiration is often modeled as being proportional to the total biomass or protein content of a plant. While it is independent of the growth rate, it is highly sensitive to environmental factors. Specifically, the rate of maintenance respiration typically increases with temperature, often following an exponential trend. Therefore, stating that it is entirely independent of temperature is incorrect.

187. (A) Continuous turnover (degradation and resynthesis) of proteins, particularly enzymes like Rubisco.
Maintenance respiration covers several metabolic activities, but the most significant portion is usually attributed to protein turnover. Enzymes and other proteins are constantly being degraded and resynthesized within the cell. In mature leaf tissue, the turnover of Rubisco, which is present in very large quantities, represents a substantial energy drain. This continuous cycle is necessary to replace damaged or aging proteins.

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188. (C) Mature, fully expanded resting leaf — Dominated by maintenance respiration.
The proportion of growth and maintenance respiration shifts during development. Young, rapidly expanding leaves have very high rates of growth respiration. As a leaf reaches its final size and expansion stops, its respiration becomes dominated by maintenance processes needed to keep the mature tissue functional. In germinating seeds, growth respiration is also very high as new tissues are rapidly formed.

189. (D) A sudden, massive decrease in the availability of all carbon substrates.
Maintenance costs increase when a plant must work harder to preserve its cellular integrity. Higher temperatures, salinity stress requiring ion pumping, and the repair of damage from heavy metals all increase the energy demand for maintenance. However, a massive decrease in the availability of carbon substrates would likely force the plant to reduce its metabolic activity and lower its respiration rate.

190. (A) I, II and V
Ecophysiologists use several methods to estimate the maintenance coefficient. One common approach is the extrapolation method, where the respiration rate is plotted against the growth rate, and the y-intercept represents maintenance. Another method involves measuring respiration in mature tissues. Correlating respiration with protein content also provides an estimate, as protein turnover is a major component of existing biomass preservation.

191. (B) The specific respiration rate is highest in young, actively growing seedlings and gradually declines as the proportion of non-metabolically active structural tissue (and reliance solely on maintenance) increases.
The specific respiration rate of a plant typically declines as it matures. Young plants and seedlings consist mostly of meristematic and rapidly growing tissues with high metabolic activity and growth respiration. As the plant develops, the proportion of structural, non-growing tissues increases. These tissues have lower overall metabolic demands and rely primarily on maintenance respiration, leading to a gradual decrease.

192. (D) High temperatures drastically increase the $Q_{\{10\}}$ of maintenance processes, causing excessive consumption of stored daily photosynthates, which can ultimately reduce overall crop yield.
Temperature has a significant impact on respiration rates. Elevated nighttime temperatures increase the rate of maintenance respiration, causing the plant to consume more of the sugars produced during the day. This reduces the net carbon gain available for the growth of new tissues or the filling of grains and fruits. This excessive respiratory loss can significantly lower the overall yield.

193. (A) Generally inhibited or reduced compared to dark respiration, partly due to a higher cytosolic ATP/ADP ratio supplied by chloroplasts and alternative internal recycling of CO_2.
Measuring mitochondrial respiration in the light is difficult because it is masked by photosynthesis and photorespiration. However, studies indicate that true mitochondrial respiration is generally lower in the light than in the dark. This inhibition is partly due to the high levels of ATP and reducing power supplied by the chloroplast, which reduces the cellular demand for mitochondrial ATP.

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194. (C) A single glycerol backbone esterified to three long-chain fatty acids.
Triacylglycerols are the primary form in which lipids are stored in plant seeds for energy. A TAG molecule consists of a single glycerol backbone that is esterified to three long-chain fatty acids. This compact and highly reduced structure allows plants to store a large amount of energy in a relatively small volume to fuel growth during the germination process.

195. (A) It takes place primarily in the plastids (chloroplasts or amyloplasts) using acetyl-CoA as the primary building block.
In plant cells, the primary site for the de novo synthesis of fatty acids is the plastid, such as the chloroplast in leaves or the amyloplast in seeds. This process utilizes acetyl-CoA and requires a supply of energy in the form of ATP and reducing power from NADPH. Once synthesized, these fatty acids are exported to the endoplasmic reticulum for further modification.

196. (D) Specialized structural amphipathic proteins known as oleosins.
Oleosomes, or lipid bodies, are specialized organelles used to store triacylglycerols. They are surrounded by a unique single layer of

phospholipids rather than a standard bilayer. This monolayer is stabilized by specialized proteins called oleosins. Oleosins are amphipathic proteins that prevent the oil droplets from coalescing and provide a binding site for the enzymes that will break down the lipids.

197. (B) Sulfolipids (SQDG) — Exclusively found in the plant central vacuole.
Plant membranes have distinct lipid compositions. Galactolipids like MGDG and DGDG are the most abundant lipids in thylakoid membranes. Phosphatidylcholine is a major component of the plasma membrane. Sulfolipids are also found in the thylakoid membranes of chloroplasts, where they are essential for photosynthesis. Stating that sulfolipids are found exclusively in the vacuole is incorrect, as they reside in plastids.

198. (C) Acetyl-CoA carboxylase (ACCase).
The breakdown of fatty acids occurs through the beta-oxidation cycle in the glyoxysomes of germinating seeds. This process involves four steps: oxidation, hydration, a second oxidation, and thiolytic cleavage. Enzymes like acyl-CoA oxidase, the multifunctional protein, and thiolase are essential. Acetyl-CoA carboxylase, however, is a regulatory enzyme involved in the synthesis of fatty acids rather than their degradation in glyoxysomes.

199. (D) The Glyoxylate cycle, utilizing isocitrate lyase and malate synthase.
In oil-rich seeds, the glyoxylate cycle is essential for converting stored fats into sugars during germination. This pathway provides a bypass of the TCA cycle's decarboxylation steps, allowing two molecules of acetyl-CoA to be converted into one molecule of succinate. Key enzymes, isocitrate lyase and malate synthase, facilitate this process within glyoxysomes. The resulting succinate is then used for gluconeogenesis.

200. (A) Oxidation (introducing a double bond) $\rightarrow$ Hydration $\rightarrow$ Second Oxidation (forming a ketone) $\rightarrow$ Thiolytic cleavage (releasing Acetyl-CoA).
A single turn of the beta-oxidation cycle systematically shortens a fatty acid chain by two carbon atoms. The sequence begins with the oxidation of the acyl-CoA to introduce a double bond. This is followed by the hydration of the double bond to form a hydroxy group. A second oxidation then converts the hydroxy group into a ketone before releasing acetyl-CoA.

201. (B) Desaturases introduce cis-double bonds into the fatty acid acyl chains, creating kinks that prevent tight packing, thereby maintaining membrane fluidity and function at lower temperatures.
When plants are exposed to low temperatures, their cell membranes can become too rigid, which impairs function. To prevent this, plants upregulate fatty acid desaturases. These enzymes introduce cis-double bonds into the acyl chains of membrane lipids. The resulting "kinks" in the fatty acids prevent them from packing tightly together, which maintains membrane fluidity and function of proteins under stress.

202. (B) Catalyze the ATP-dependent carboxylation of acetyl-CoA to form malonyl-CoA, the committed first step in de novo fatty acid synthesis.
Acetyl-CoA carboxylase is the key regulatory enzyme for fatty acid biosynthesis in plants. It catalyzes the first committed step of the pathway, which is the ATP-dependent addition of carbon dioxide to acetyl-CoA to form malonyl-CoA. This malonyl group then serves as the donor for the two-carbon units used to elongate the growing fatty acid chain during synthesis in plastids.

203. (A) In plants, it occurs exclusively in peroxisomes/glyoxysomes, whereas in animals, it occurs primarily in mitochondria.
There is a significant difference in the localization of fatty acid degradation between plant and animal cells. In animals, beta-oxidation occurs primarily within the mitochondria. However, in plants, this process is localized exclusively within specialized peroxisomes, which are called glyoxysomes in germinating seeds. Plant mitochondria do not possess the enzymes necessary for beta-oxidation, meaning it occurs only in peroxisomes.

204. (C) Cutin is a polyester composed primarily of hydroxy and epoxy fatty acids, whereas suberin is a highly complex heteropolymer containing both aliphatic (long-chain fatty acid derivatives) and significant aromatic (phenolic) domains.
Cutin and suberin are two major hydrophobic polymers used by plants to create barriers. Cutin is found on the outer surfaces of leaves and is a polyester made mostly of hydroxy and epoxy

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fatty acids. Suberind is found in roots and bark. It is more complex than cutin, containing both an aliphatic polyester domain and a significant polyaromatic domain structurally related to lignin.

205. (A) De novo synthesis of C16/C18 fatty acids in the plastid → Export to the ER → Elongation into Very-Long-Chain Fatty Acids (VLCFAs) → Modification (e.g., decarbonylation to alkanes or reduction to primary alcohols) → Export to the cuticle.
The production of epicuticular waxes begins in the plastids with the synthesis of common sixteen or eighteen-carbon fatty acids. These are exported to the endoplasmic reticulum, where they are elongated into very-long-chain fatty acids. These precursors are modified through different pathways to produce alkanes, alcohols, or esters. Finally, the finished wax components are transported to the plasma membrane and exuded.

206. (C) Suberin.
The Casparian strip is a specialized band of cell wall material found in the endodermis of plant roots. Its primary function is to block the apoplastic movement of water and solutes, forcing them to pass through the plasma membrane of the endodermal cells. This selectivity is achieved because the Casparian strip is impregnated with suberin, a hydrophobic and waxy polymer.

207. (B) Waxes are exuded strictly as fully formed microscopic solid crystals directly from the Golgi apparatus onto the leaf surface.
Epicuticular waxes often form intricate microscopic crystals on the surfaces of leaves and stems. These structures are not formed inside the cell. Instead, the individual wax components are exuded onto the surface in a liquid or semi-liquid state and then self-assemble into diverse three-dimensional shapes, such as tubes or plates, as they solidify according to their chemical composition.

208. (D) Suberin — Restricts apoplastic water movement in the endodermis and seals wounded tissues.
Plant surface polymers have vital protective roles. Cutin and waxes primarily protect leaves from water loss and UV damage. Suberin is especially important in roots and wounded tissues. In the root endodermis, it forms the Casparian strip which restricts apoplastic water movement. Suberin also acts as a primary component of the periderm and seals wounds to prevent pathogen entry.

209. (A) Serving as the primary site for active absorption of macronutrients from the atmosphere.
The plant cuticle and its associated waxes provide a suite of protective functions, including minimizing non-stomatal water loss, reflecting harmful UV radiation, and providing a self-cleaning surface. However, they are designed as barriers rather than sites of absorption. While some small molecules can penetrate the cuticle, it is not the primary site for the active absorption of macronutrients from the atmosphere.

210. (A) I, II, IV and V
Suberized cell walls are complex structures containing both polyaromatic and polyaliphatic domains. They are highly impermeable to water and solutes and can restrict the diffusion of gases, which is important in root nodules. Unlike the cuticle, which is deposited on the outside of the leaf, suberin lamellae are typically deposited on the inner side of the primary cell wall.

211. (A) They are transported across the plasma membrane by ABC transporters and shuttled through the cell wall by Lipid Transfer Proteins (LTPs).
Moving hydrophobic wax components from the endoplasmic reticulum to the leaf surface is a logistical challenge. Current models suggest that these molecules are transported across the plasma membrane by specialized ATP-binding cassette transporters. Once in the aqueous environment of the cell wall, the waxes are believed to be carried by lipid transfer proteins that shield the molecules from water.

212. (D) They are the direct obligate precursors for the vast majority of wax components, including alkanes, secondary alcohols, and wax esters.
Very-long-chain fatty acids, which contain more than twenty carbon atoms, are the essential building blocks for most wax components. They are synthesized in the endoplasmic reticulum through the repeated addition of two-carbon units. These VLCFAs then enter metabolic branches where they are either reduced to form alcohols and esters or decarbonylated to produce alkanes, secondary alcohols, and ketones.

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213. (B) Phenylalanine, Tyrosine, and Tryptophan.
The Shikimate pathway is a fundamental biosynthetic route found in plants, bacteria, and fungi, but absent in animals. It serves as the bridge between primary metabolism and the synthesis of many specialized compounds. Its most direct and essential function is to provide the carbon skeletons for the three aromatic amino acids: phenylalanine, tyrosine, and tryptophan required for protein synthesis.

214. (C) The MVA pathway is localized in the cytosol/ER, while the MEP pathway is localized in the plastids.
Plants use two distinct pathways to synthesize the five-carbon building blocks for all terpenes. The mevalonate pathway is located in the cytosol and endoplasmic reticulum and is primarily responsible for producing sterols and sesquiterpenes. The methylerythritol phosphate pathway is located in the plastids and provides the precursors for monoterpenes, diterpenes, and the phytol chain of chlorophyll.

215. (D) It competitively inhibits 5-enolpyruvylshikimate-3-phosphate (EPSP) synthase, a key enzyme in the Shikimate pathway.
Glyphosate is a widely used broad-spectrum herbicide that targets a specific enzyme in the Shikimate pathway. It acts as a competitive inhibitor of five-enolpyruvylshikimate-three-phosphate synthase, which is necessary for the production of the three aromatic amino acids. By blocking this enzyme, glyphosate starves the plant of essential building blocks for proteins and vital secondary metabolites, leading to death.

216. (A) Tannins — Derived exclusively from the direct degradation of unbroken fatty acids.
Different classes of secondary metabolites arise from specific pathways. Monoterpenes and diterpenes come from the MEP pathway, while sesquiterpenes often come from the MVA pathway. Lignin and other phenylpropanoids are derived from phenylalanine via the Shikimate pathway. Tannins are complex phenolic compounds also derived from the Shikimate and phenylpropanoid pathways. The idea that they are derived from fatty acids is incorrect.

217. (B) RuBP directly bypassing the Calvin cycle to form alkaloids.
Secondary metabolites are synthesized from intermediates of primary metabolism. The Shikimate pathway uses erythrose-four-phosphate and PEP. The mevalonate and malonate pathways use acetyl-CoA. The MEP pathway uses pyruvate and glyceraldehyde-three-phosphate. While RuBP is essential for the Calvin cycle in the chloroplast, it is not a direct starting point for the synthesis of alkaloids or other major secondary metabolites.

218. (B) They undergo a highly ordered, sequential "head-to-tail" condensation to form generic prenyl diphosphates (e.g., GPP, FPP, GGPP).
Terpenes are built from five-carbon isoprene units in a highly controlled manner. Enzymes called prenyltransferases catalyze the sequential condensation of these units, usually in a head-to-tail fashion. This produces basic intermediates with different chain lengths, such as ten-carbon geranyl diphosphate or fifteen-carbon farnesyl diphosphate. These generic precursors are then further modified by specific cyclases to create diversity.

219. (A) Light stimulates photosynthesis, generating plastidic pyruvate, GAP, and reducing power (ferredoxin/NADPH), which strongly upregulate the MEP pathway flux to support massive synthesis of carotenoids and phytol.
The MEP pathway is located in the plastid and is closely tied to the light reactions of photosynthesis. Light provides the necessary substrates, such as pyruvate and GAP, and the reducing power and ATP needed for the pathway. Consequently, light exposure strongly upregulates the flux through this pathway. This coordination ensures that the plant can produce essential carotenoids and chlorophyll.

220. (C) Catalyzes the non-oxidative deamination of L-phenylalanine to form trans-cinnamic acid and free ammonia, representing the gateway to all phenylpropanoid metabolism.
Phenylalanine ammonia-lyase is a central enzyme in plant specialized metabolism. It catalyzes the first step of the phenylpropanoid pathway by removing an ammonia molecule from the amino acid L-phenylalanine to form trans-cinnamic acid. This reaction is the major gateway for carbon flow from primary metabolism into the synthesis of a huge array of phenolic compounds, including lignin and flavonoids.

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221. (D) Sesquiterpenes (C15) and triterpenes (C30) like sterols are primarily synthesized from MVA-derived precursors (FPP) in the cytosol/ER.
Terpene synthesis is spatially organized within the plant cell. Sesquiterpenes and triterpenes, including essential sterols and brassinosteroids, are primarily synthesized in the cytosol and endoplasmic reticulum using precursors from the mevalonate pathway. In contrast, smaller monoterpenes and larger diterpenes are typically produced in the plastids via the MEP pathway. Each class of terpenes has a predominant site of synthesis.

222. (C) 20 carbon atoms.
Terpenes are classified based on the number of five-carbon isoprene units they contain. A monoterpene has two units, giving it ten carbon atoms. A sesquiterpene has three units and fifteen carbons. A diterpene is composed of four isoprene units, which results in a total of twenty carbon atoms. Examples of important diterpenes in plants include the hormone gibberellin and phytol.

223. (B) The three main monolignol building blocks are strictly straight-chain saturated fatty alcohols.
Lignin is a complex and rigid polymer that strengthens the cell walls of vascular plants. It is formed by the oxidative coupling of three main types of monolignols: p-coumaryl, coniferyl, and sinapyl alcohols. These building blocks are aromatic compounds derived from the phenylpropanoid pathway, not straight-chain saturated fatty alcohols. Proportions vary between species and determine physical properties and durability.

224. (D) Spatial compartmentalization is disrupted, allowing endogenous β-glycosidases and hydroxynitrile lyases to sequentially cleave the glycoside, rapidly releasing toxic hydrogen cyanide (HCN) gas.
Cyanogenic glycosides are a form of chemical defense that uses a binary system. In intact tissue, the glycosides and the enzymes that break them down are stored in different compartments. When an herbivore eats the plant, the cells are crushed and the components mix. This results in a rapid chemical reaction that releases toxic hydrogen cyanide gas, inhibiting cellular respiration.

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225. (A) Morphine — Synthesized by the opium poppy, acts as a potent analgesic acting on the central nervous system.
Alkaloids are a diverse group of nitrogen-containing compounds with many biological activities. Morphine, produced by the poppy plant, is a classic example of an alkaloid with potent medicinal properties, acting on pain receptors in the nervous system. Other alkaloids like nicotine also have significant effects. While many serve defensive roles, they are not typically herbicides targeting other plants.

226. (C) Glucosinolates.
Plants produce a wide variety of phenolic compounds characterized by having at least one aromatic ring with a hydroxyl group. Major sub-classes include flavonoids, anthocyanins, and coumarins. Glucosinolates, however, are a different class of secondary metabolites. They contain sulfur and nitrogen and are particularly common in the cabbage family. Their biosynthetic origin and chemical structure are distinct from phenylpropanoids.

227. (A) The spatial separation of stable glucosinolates (in vacuoles) and the enzyme myrosinase (in specialized idioblasts); tissue crushing mixes them, producing toxic, pungent isothiocyanates.
The mustard oil bomb is a defensive strategy used by plants in the order Brassicales. It involves the storage of glucosinolates and the enzyme myrosinase in separate cells or compartments. Damage to the plant tissue by an herbivore causes the components to mix, triggering enzymatic hydrolysis. This reaction produces highly reactive and pungent compounds like isothiocyanates, which are toxic to insects.

228. (D) Upon perception of pathogen elicitors, defensive signaling pathways are activated, leading to the rapid, localized de novo synthesis of these antimicrobial compounds to halt the infection.
Phytoalexins are antimicrobial secondary metabolites that are part of the plant's induced defense system. Unlike constitutive defenses that are always present, phytoalexins are synthesized de novo only when the plant perceives an attack. Recognition of elicitors from a pathogen triggers a signaling cascade that activates synthesis genes. This allows the plant to concentrate its resources precisely where they are needed.

229. (B) Polymers of flavonoid units (e.g., catechin) linked by resilient carbon-carbon bonds, requiring harsh oxidative conditions for cleavage.
Tannins are phenolic polymers that can bind to and precipitate proteins. Condensed tannins, also known as proanthocyanidins, are formed by the polymerization of flavonoid units like catechin. Unlike hydrolyzable tannins, which have ester bonds easily broken by acid, condensed tannins are held together by strong carbon-carbon bonds. This makes them much more resistant to degradation and persistent in herbivores.

230. (C) They act as "indirect defense" signals that attract parasitic wasps or predatory mites to prey on the caterpillar.
Plants can defend themselves indirectly by communicating with other organisms. When certain caterpillars feed on a leaf, the plant may emit a specific blend of volatile terpenes. These chemicals do not necessarily poison the caterpillar directly. Instead, they act as an airborne signal that is picked up by the natural enemies of the herbivore, which then locate and attack.

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CHAPTER 03
Crop Productivity and Modelling

2023

1. Which historical concept first established the relationship between dry matter accumulation and water transpired by a crop?
(A) De Wit's crop modeling
(B) Briggs and Shantz ratio
(C) Donald's ideotype concept
(D) Duncan's canopy model

2024

2. What physiological phase in rice growth is most sensitive to environmental stress regarding spikelet fertility?
(A) Meiosis and heading
(B) Active tillering
(C) Panicle initiation
(D) Dough stage

2016

3. Which of the following is an INCORRECT statement regarding physiological constraints in major pulses?
(A) Flower abscission reduces the potential yield in many pulse species
(B) Indeterminate growth patterns create severe source-sink competition
(C) High harvest index is common in traditional landraces
(D) Root nodule activity is largely independent of immediate soil nitrogen levels

2024

4. In groundnut, which developmental process acts as the primary sink during the later stages of reproductive growth?
(A) Peg elongation
(B) Nodule formation
(C) Primary branching
(D) Pod development

2017

5. Consider the following statements regarding Passioura's yield equation:
I. It is defined as Yield = Transpiration × Transpiration Efficiency × Harvest Index.
II. Transpiration efficiency is independent of vapor pressure deficit.
III. Harvest index represents the ratio of economic yield to biological yield.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I and III
(C) II
(D) III

2010

6. Duncan's crop growth model primarily mathematically simulates which of the following processes?
(A) Modeling the kinetics of root nutrient uptake in the soil
(B) Canopy photosynthesis based on leaf angle and LAI values
(C) Simulating the loading of phloem in indeterminate crop types
(D) Estimating the rates of nitrogen fixation in root nodules

2021

7. The Relative Growth Rate (RGR) of a crop is mathematically defined as:
(A) The increase in leaf area per unit ground area over time
(B) The dry matter accumulation per unit leaf area over time
(C) The absolute growth measured over the entire crop duration
(D) The plant material increase per unit material per unit time

2006

8. Which parameter best represents the total duration of the photosynthetic apparatus active over a growing season?
(A) Leaf Area Duration
(B) Net Assimilation Rate
(C) Leaf Area Index
(D) Specific Leaf Area

2010

9. Specific Leaf Weight (SLW) is most closely positively correlated with which physiological trait?
(A) Total root system length
(B) Rate of flower abscission

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(C) Photosynthetic capacity per unit leaf area
(D) Intercellular carbon dioxide depletion

2021

10. The following question consists of two statements—Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): Harvest Index (HI) cannot exceed 1.0 in any agricultural crop.
Reason (R): HI is the fraction of total biological yield that is partitioned to the economic part.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2013

11. Which yield component typically compensates the least when main tiller density is low in wheat?
(A) Number of grains per spike
(B) Spikelet number per spike
(C) Number of fertile tillers per plant
(D) Grain test weight

2007

12. Phloem loading in most crop plants primarily transports which of the following carbohydrates?
(A) Glucose
(B) Sucrose
(C) Fructose
(D) Starch

2009

13. Erect leaf orientation in canopy architecture provides which primary advantage in dense crop stands?
(A) It facilitates complete shading of lower leaf layers
(B) It results in increased individual transpiration efficiency
(C) Improved penetration of light into the lower canopy
(D) It causes a reduction in the total biological yield

2011

14. According to the Beer-Lambert law, a lower light extinction coefficient (k) implies:
(A) Horizontal leaf orientation
(B) Rapid light attenuation in the upper canopy
(C) Zero net assimilation rate
(D) Deeper light penetration into the canopy

2004

15. Consider the following statements regarding Leaf Area Index (LAI):
I. Optimum LAI is where crop growth rate is maximal.
II. Critical LAI occurs when 95% of incident light is intercepted.
III. Respiration increases as LAI increases.
IV. Optimum LAI is typically higher than Critical LAI.
Which of the above statement(s) is/are correct?
(A) I, II, and III
(B) II and IV
(C) I and III
(D) III and IV

2015

16. An increase in Vapor Pressure Deficit (VPD) typically leads to which physiological response in crop plants?
(A) Increased stomatal conductance
(B) Stomatal closure
(C) Decreased transpiration rate
(D) Enhanced carbon assimilation

2015

17. Which phenomenon describes the interaction of day length and temperature in controlling floral initiation?
(A) Phototropism
(B) Photothermal response
(C) Thermoperiodicity
(D) Vernalization

2001

18. Growing Degree Days (GDD) are calculated by subtracting the base temperature from the:
(A) Mean daily temperature
(B) Maximum daily temperature
(C) Minimum daily temperature
(D) Optimum daily temperature

NODIA

2002

19. Photothermal Units (PTU) mathematically integrate Thermal Time with which environmental variable?
(A) Total solar radiation
(B) Maximum daily humidity
(C) Day length
(D) Wind speed

2010

20. Match the crop ideotype concepts in List I with their primary features in List II:
List I: (Ideotype Concept)
P. Donald's Wheat Ideotype

Q. New Plant Type Rice
R. Groundnut Ideotype
S. Cotton Ideotype

List II: (Primary Feature)

1. Low tillering, heavy panicles
2. Short stature, erect leaves, single culm
3. Short internodes, zero monopodia
4. Compact canopy, sequential branching

(A) P-2, Q-1, R-4, S-3
(B) P-1, Q-2, R-3, S-4
(C) P-2, Q-4, R-1, S-3
(D) P-3, Q-1, R-4, S-2

2002

21. Which trait is LEAST relevant when designing a physiological selection index for drought tolerance?
(A) High water use efficiency traits
(B) Depth of the root system
(C) High stomatal conductance under stress
(D) Osmotic adjustment capacity

2017

22. Infrared Gas Analyzers (IRGA) measure photosynthesis primarily by detecting changes in the concentration of:
(A) Oxygen
(B) Carbon dioxide
(C) Water vapor
(D) Nitrogen

2023

23. Which instrument is specifically used for non-destructive estimation of leaf chlorophyll content?
(A) Ceptometer
(B) Porometer
(C) IRGA
(D) SPAD meter

2005

24. What best defines the harvest index of a crop?
(A) The ratio of economic yield to above-ground biological yield
(B) The ratio of grain yield to total economic yield
(C) The absolute dry matter accumulated at maturity
(D) The efficiency of carbon fixation during reproduction

2001

25. Consider the following statements concerning sink strength:
I. Sink strength equals sink size multiplied by sink activity.
II. Sink activity is driven by phloem unloading enzymes.
III. Sucrose synthase is a key enzyme for sink activity.
IV. High sink strength stimulates source activity.
V. Sink size is determined primarily by cell number.

Which of the above statement(s) is/are correct?
(A) I, II, III and IV
(B) I, II, III and V
(C) II, III, IV and V
(D) I, III and V

2007

26. Which structural element is a major physiological constraint in wheat yield under high-temperature stress during anthesis?
(A) Pollen sterility
(B) Prolonged vegetative growth
(C) Excessive flag leaf expansion
(D) Increased tillering

2006

27. Indeterminate growth in soybean causes which specific physiological conflict?
(A) The early termination of root growth activity
(B) Premature senescence of the lowest leaf layers
(C) The inhibition of active nodule formation
(D) Competition between new leaves and developing pods

2018

28. In mustard, the most critical stage for source limitation affecting final oil yield is:
(A) Seedling stage
(B) Siliqua development
(C) Rosette stage
(D) Bolting

2005

29. Transpiration Efficiency is most directly improved by which physiological modification?
(A) Decreasing individual mesophyll conductance
(B) Lowering the specific leaf area significantly
(C) Reducing stomatal conductance more than assimilation
(D) Increasing the root-to-shoot biomass ratio

2003

30. The following question consists of two statements—Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): CGR increases continuously until maturity and rarely declines.

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Reason (R): Lower leaves in a dense canopy eventually fall below the light compensation point.

(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2004

31. Crop Growth Rate (CGR) is derived by multiplying Net Assimilation Rate (NAR) by:
(A) Leaf Area Index (LAI)
(B) Specific Leaf Area (SLA)
(C) Relative Growth Rate (RGR)
(D) Harvest Index (HI)

2015

32. A decrease in Net Assimilation Rate (NAR) during later stages of crop growth is primarily due to:
(A) Increased specific leaf weight
(B) Mutual shading of leaves
(C) Enhanced root respiration
(D) Increased photoperiod

2024

33. Which parameter describes the leaf area constructed per unit of leaf dry biomass?
(A) Specific Leaf Weight
(B) Specific Leaf Area
(C) Leaf Area Ratio
(D) Leaf Weight Ratio

2005

34. Biological yield is best described as the sum of:
(A) Economic yield and above-ground vegetative biomass
(B) Economic yield and root biomass
(C) Total grain weight and harvest index
(D) Grain yield and root exudates

2021

35. Select the correct sequence of stages in the calculation of Harvest Index:
(A) Measure grain dry weight → Measure above-ground dry weight → Calculate ratio
(B) Measure above-ground dry weight → Measure grain dry weight → Calculate ratio
(C) Measure total plant wet weight → Measure grain wet weight → Calculate ratio
(D) Measure root biomass → Measure grain biomass → Calculate ratio

2012

36. Test weight in cereals is a direct measure of which yield component?
(A) Number of spikes per square meter
(B) Number of spikelets per spike
(C) Tillering efficiency
(D) Individual grain size and density

2013

37. Which mechanism is primarily responsible for phloem unloading in storage sinks like developing seeds?
(A) Symplastic passive diffusion
(B) Apoplastic active transport
(C) Xylem-to-phloem transfer
(D) Transpirational pull

NODIA

2017

38. A high light extinction coefficient (k) is typically associated with canopies that possess:
(A) Erect leaves
(B) Highly clumped leaves
(C) Horizontal leaves
(D) Small, needle-like leaves

2008

39. Which variable is NOT a direct component of the Beer-Lambert equation for light interception?
(A) Incident radiation
(B) Extinction coefficient
(C) Leaf Area Index
(D) Transpiration rate

2003

40. Match the measurement instruments in List I with their corresponding parameters in List II:
List I: (Instrument)
P. Ceptometer
Q. Porometer
R. SPAD meter
S. Leaf area meter
List II: (Parameter)
1. Stomatal conductance
2. PAR interception
3. Destructive leaf surface area
4. Relative chlorophyll content
(A) P-2, Q-1, R-4, S-3
(B) P-1, Q-2, R-3, S-4
(C) P-3, Q-4, R-1, S-2
(D) P-2, Q-4, R-1, S-3

2001

41. At the critical Leaf Area Index, the Net Assimilation Rate (NAR) of the lowest canopy leaves is:
(A) Highly positive

(B) Exactly zero
(C) Highly negative
(D) Equal to the canopy average

2008

42. High Vapor Pressure Deficit (VPD) restricts crop yield primarily by causing:
(A) Enhanced photoinhibition
(B) Reduced CO_2 diffusion into leaves
(C) Increased night respiration
(D) Premature flower initiation

2001

43. Short-day plants will initiate flowering when the night length is:
(A) Longer than a critical duration
(B) Shorter than a critical duration
(C) Equal to the day length
(D) Continuously interrupted by far-red light

2012

44. The Base Temperature for calculating GDD in wheat is generally accepted to be approximately:
(A) 0-5 °C
(B) 10-15 °C
(C) 15-20 °C
(D) 25-30 °C

2002

45. Arrange the following crop phenology phases in correct order for rice, then select the matching option:
1. Booting
2. Anthesis
3. Panicle Initiation
4. Dough stage

(A) 3, 1, 2, 4
(B) 1, 3, 2, 4
(C) 3, 2, 1, 4
(D) 1, 2, 3, 4

2007

46. Heliothermal Units (HTU) differ from GDD by additionally incorporating which factor?
(A) Photoperiod duration
(B) Relative humidity
(C) Actual bright sunshine hours
(D) Soil temperature

2007

47. Donald's original wheat ideotype featured which characteristic to minimize intra-plant competition?
(A) A highly branched structure
(B) A single uniculm stem
(C) Horizontal leaf orientation
(D) High specific leaf area

2019

48. The "New Plant Type" (NPT) rice developed at IRRI aimed to increase yield potential primarily by:
(A) Increasing the number of unproductive tillers
(B) Reducing total panicle weight
(C) Increasing plant height dramatically
(D) Producing fewer but highly productive tillers

2005

49. Which index is used to select for physiological efficiency under competitive field conditions?
(A) Crop growth rate at full canopy
(B) Single plant isolated yield
(C) Maximum individual leaf area
(D) Main root elongation rate

2025

50. Consider the following statements regarding IRGA principles:
I. It utilizes the selective absorption of infrared radiation by CO_2.
II. It measures the net change in O_2 concentration across a leaf chamber.
III. Photosynthesis is detected when Sample CO_2 concentration exceeds Reference CO_2.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I only
(D) III only

2024

51. Porometers assess stomatal behavior by directly measuring the rate of:
(A) Carbon dioxide uptake
(B) Light transmission through the epidermis
(C) Heat dissipation from the leaf surface
(D) Water vapor diffusion from the leaf

2022

52. What physiological shift characterizes the transition from vegetative to reproductive growth in cereals?
(A) Sink dominance shifts from leaves to roots
(B) Apical meristem differentiation into floral primordia
(C) Complete cessation of photosynthesis
(D) Drastic reduction in harvest index

2017

53. Under drought stress, which pulse crop mechanism most heavily consumes assimilates to maintain nitrogen fixation?

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(A) Stomatal opening
(B) Leaf rolling
(C) Stem elongation
(D) Nodule oxygen permeability regulation

2024

54. In oilseed crops, the energetic cost of synthesizing lipids compared to carbohydrates results in:
(A) Higher absolute seed yield per gram of photosynthate
(B) Identical harvest indices across all oilseeds
(C) Reduced carbon assimilation requirements
(D) Lower absolute seed yield per gram of photosynthate

2002

55. Which component of Passioura's equation is most heavily targeted when breeding for drought escape?
(A) Transpiration Efficiency
(B) Total Transpiration
(C) Harvest Index
(D) Stomatal density

2011

56. Duncan's mathematical simulation requires which primary structural input to predict canopy photosynthesis?
(A) Root depth distribution
(B) Leaf angle distribution
(C) Phloem transport velocity
(D) Nodule mass per plant

2010

57. The formula $RGR = NAR \times LAR$ indicates that Relative Growth Rate is dependent on:
(A) Only physiological efficiency
(B) Only canopy architecture
(C) Solely on the total biological yield
(D) Both physiological efficiency and morphological leaf allocation

2012

58. Leaf Area Duration (LAD) is mathematically represented as the integral of:
(A) LAI over time
(B) RGR over time
(C) NAR over space
(D) SLA over light intensity

2004

59. High Specific Leaf Weight (SLW) leaves generally exhibit:
(A) Thinner mesophyll layers
(B) Lower light saturation points
(C) Higher concentrations of RuBisCO per unit area
(D) Increased susceptibility to mechanical tearing

2006

60. Consider the following statements concerning assimilate partitioning:
I. Leaves are the primary sources during vegetative stages.
II. Phloem loading moves assimilates against a concentration gradient.
III. Developing seeds are strong sinks that utilize apoplastic unloading.
IV. Xylem is the primary conduit for carbohydrate transport to seeds.
Which of the above statement(s) is/are correct?
(A) I, II and III
(B) II, III and IV
(C) I and III
(D) I, II, III and IV

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2009

61. Sink size in a cereal grain is predominantly determined by cell division during which phase?
(A) Late grain filling
(B) Physiological maturity
(C) Vegetative tillering
(D) Pre-anthesis and early post-anthesis

2013

62. Which phyllotaxy arrangement minimizes mutual shading in a vertically structured canopy?
(A) Alternate/Spiral
(B) Opposite
(C) Whorled
(D) Decussate

2009

63. A canopy with a light extinction coefficient (k) of 0.3 allows for:
(A) Complete light block by the upper leaves
(B) Uniform light distribution down to the lower leaves
(C) Maximum mutual shading
(D) Zero interception of PAR

2018

64. In determining optimum LAI, as LAI increases beyond the optimum point, what occurs?
(A) Crop growth rate remains constant
(B) Net assimilation rate increases
(C) Light interception dramatically decreases
(D) Crop growth rate decreases

2013

65. The primary cause of reduced crop productivity under high Vapor Pressure Deficit (VPD) is:
(A) Excessive cooling of the leaf surface
(B) Increased efficiency of RuBisCO
(C) Enhanced root water uptake
(D) Closure of stomata to prevent dehydration

2010

66. Thermoperiodicity dictates that many crops require:
(A) Constant temperatures day and night for optimal growth
(B) A diurnal fluctuation between day and night temperatures
(C) Freezing temperatures to initiate germination
(D) Only extreme high temperatures to trigger flowering

2008

67. The calculation of Growing Degree Days (GDD) assumes:
(A) An exponential relationship between growth and extreme heat
(B) That day length controls all thermal responses
(C) Growth occurs independently of mean temperature
(D) A linear relationship between growth and temperature above a base

2003

68. Photothermal Units (PTU) are primarily utilized to model which aspect of crop physiology?
(A) Phenological development and flowering time
(B) Root mass accumulation
(C) Final grain nitrogen content
(D) Lipid synthesis pathways

2003

69. A physiological selection index for improving lodging resistance in cereals would heavily weight:
(A) High specific leaf area
(B) Tall plant stature
(C) Increased lower internode diameter and stem wall thickness
(D) Shallow root systems

2018

70. Consider the following statements concerning Ceptometers:
I. They measure Photosynthetically Active Radiation (PAR).
II. They consist of a linear array of sensors.
III. They estimate LAI by measuring fractional light interception.
IV. They destructively sample leaf tissue.
V. They utilize the Beer-Lambert law in their LAI calculations.
Which of the above statement(s) is/are correct?
(A) I, II, III and V
(B) II, III, IV and V
(C) I, III and IV
(D) I, II, IV and V

2023

71. IRGA systems can be configured to measure transpiration simultaneously by incorporating:
(A) An oxygen sensor
(B) A thermocouple for root temperature
(C) A chlorophyll fluorometer
(D) A water vapor analyzer (H_2O IRGA)

2016

72. Leaf area meters measure total area by utilizing:
(A) Pressure displacement chambers
(B) An optical scanner and a conveyor belt
(C) Acoustic resonance sensors
(D) Gas exchange differentials

2009

73. Which environmental factor is considered the ultimate primary determinant of potential crop yield in an optimal disease-free environment?
(A) Soil micronutrients
(B) Wind velocity
(C) Total intercepted solar radiation
(D) Ambient oxygen concentration

2004

74. During grain filling in wheat, what serves as a significant secondary source of assimilates if leaves senesce early?
(A) Root storage parenchyma
(B) Floral nectaries
(C) Nodule carbohydrates
(D) Stem internode reserves

2015

75. The energy-intensive process of biological nitrogen fixation limits the theoretical maximum yield of legumes compared to cereals because:
(A) Nitrogenase requires ATP and reducing equivalents
(B) Nodules fix carbon instead of nitrogen
(C) Legumes lack the Calvin cycle
(D) Cereals do not require nitrogen for growth

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2009

76. Soybean exhibits a drop in physiological efficiency during late pod filling predominantly due to:
(A) "Self-destruction" hypothesis where nutrients are heavily mobilized from leaves
(B) Rapid expansion of new vegetative branches
(C) Complete cessation of transpiration
(D) Enhanced root nodule proliferation

2019

77. To maximize the Harvest Index in Passioura's equation under limited water, a crop should ideally:
(A) Exhaust all water during vegetative growth
(B) Maximize early vegetative canopy size indefinitely
(C) Minimize post-anthesis photosynthesis
(D) Save a portion of soil moisture for the reproductive phase

2017

78. Duncan's model emphasizes that canopy photosynthesis is maximized when upper leaves are:
(A) Erect to allow light penetration
(B) Horizontal
(C) Clustered tightly together
(D) Broad and thin

2018

79. A constant Relative Growth Rate (RGR) indicates that plant biomass is increasing:
(A) Linearly
(B) Logarithmically
(C) Exponentially
(D) Quadratically

2008

80. The following question consists of two statements—Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): CGR and LAI show a linear relationship up to the critical LAI.
Reason (R): Beyond critical LAI, the addition of leaf area significantly increases mutual shading without increasing light interception.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2023

81. In defining Net Assimilation Rate (NAR), the parameter primarily reflects the efficiency of:
(A) The root system
(B) Phloem loading mechanisms
(C) Seed nutrient storage
(D) The photosynthetic machinery per unit leaf area

2009

82. Which environmental condition generally results in a higher Specific Leaf Weight (SLW) in developing leaves?
(A) High solar irradiance
(B) Heavy shading
(C) Continuous flooding
(D) Extremely high planting density

2014

83. The transition from biological yield accumulation to economic yield accumulation marks the onset of:
(A) Germination
(B) Reproductive partitioning
(C) Active tillering
(D) Vernalization

2010

84. Which yield component is determined earliest in the life cycle of a maize crop?
(A) Kernel weight
(B) Total grain protein
(C) Harvesting moisture
(D) Number of kernel rows per ear

2015

85. Sink limitation in crop physiology implies that yield is restricted by:
(A) Insufficient leaf area
(B) The inability of developing organs to utilize available assimilates
(C) Low stomatal conductance
(D) Poor light interception

2016

86. Leaf rolling in rice under water deficit specifically functions to:
(A) Increase the effective leaf area for photosynthesis
(B) Decrease the effective leaf area to reduce transpiration
(C) Enhance light interception on the abaxial surface
(D) Promote phloem transport

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2010

87. Under the Beer-Lambert law, light intensity at depth L inside the canopy follows which mathematical decay function?
(A) Linear
(B) Sigmoidal
(C) Polynomial
(D) Exponential

2022

88. Optimum LAI varies significantly depending on the crop's:
(A) Leaf angle and canopy architecture
(B) Root nodule color
(C) Base temperature requirement
(D) Photoperiodic classification

2005

89. Elevated VPD affects the transpiration efficiency of a leaf by:
(A) Eliminating stomatal resistance entirely
(B) Forcing the stomata to remain fully open at night
(C) Driving a faster rate of water loss per unit of CO_2 gained
(D) Decreasing the rate of water loss per unit of CO_2 gained

2013

90. Match the crop in List I with its photoperiodic classification in List II:
List I: (Crop)
P. Wheat
Q. Soybean
R. Day-neutral tomato
S. Sugarcane (flowering)
List II: (Photoperiodic Classification)
1. Long-day plant
2. Short-day plant
3. Day-neutral plant
4. Intermediate-day plant
(A) P-1, Q-2, R-3, S-4
(B) P-2, Q-1, R-3, S-4
(C) P-1, Q-3, R-2, S-4
(D) P-3, Q-1, R-4, S-2

2022

91. Vernalization requirements in winter wheat ensure that flowering:
(A) Occurs before winter freezing
(B) Is strictly dependent on high humidity
(C) Happens immediately after seedling emergence
(D) Occurs only after a prolonged period of cold

2004

92. The formula for calculating daily GDD is:
(A) $\frac{T_{\max} + T_{\min}}{2} - T_{base}$
(B) $\frac{T_{\max} - T_{\min}}{T_{base}}$
(C) $T_{\max} - \frac{T_{\min} + T_{base}}{2}$
(D) $\frac{T_{\max} \times T_{\min}}{T_{base}}$

2018

93. HTU calculation modifies the PTU framework by explicitly accounting for:
(A) Nighttime temperatures
(B) Soil moisture deficits
(C) CO_2 concentration
(D) Cloud cover via bright sunshine hours

2015

94. The New Plant Type (NPT) rice model hypothesized that eliminating unproductive tillers would:
(A) Reduce intra-plant competition and increase harvest index
(B) Decrease total sink capacity
(C) Cause rapid premature leaf senescence
(D) Drastically increase the optimal LAI requirement

2011

95. Physiological breeding utilizes canopy temperature depression (CTD) as an index to select for:
(A) High frost tolerance
(B) Resistance to waterlogging
(C) Low specific leaf area
(D) Deep root activity and stomatal conductance under heat/drought

2021

96. Which operational mode of an IRGA allows for the most precise measurement of leaf photosynthesis?
(A) Closed static system
(B) Open gas exchange system with precise flow control
(C) Destructive vacuum extraction
(D) Passive diffusion chambers

2006

97. The SPAD meter estimates chlorophyll content by measuring the transmittance of leaf tissue at which two wavelengths?
(A) Ultraviolet and Green
(B) Red and Near-Infrared

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(C) Blue and Far-Red
(D) Yellow and Microwave

2004

98. The specific application of a steady-state porometer involves measuring:
(A) Total leaf area
(B) The resistance to water vapor flux from the leaf
(C) Carbon isotope discrimination
(D) Nitrate reductase activity

2003

99. Which phase of wheat growth exhibits the maximum relative growth rate (RGR)?
(A) Early seedling to tillering
(B) Anthesis
(C) Dough stage
(D) Physiological maturity

2011

100. Consider the following statements regarding pulse crop limitations:
I. Flower abscission can exceed 80% in pigeonpea.
II. Determinate types suffer less from vegetative-reproductive competition.
III. Nodule senescence happens primarily during seedling emergence.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I and III
(C) II
(D) III

2022

101. Which morphological structure forms the primary sink in mustard during the final phase of its life cycle?
(A) The taproot
(B) The rosette leaves
(C) The apical meristem
(D) The siliqua and seeds

2008

102. Transpiration Efficiency (TE) is mathematically equivalent to:
(A) $\frac{\text{Total water applied}}{\text{Harvest index}}$
(B) $\frac{\text{Biological yield}}{\text{Total water transpired}}$
(C) $\frac{\text{Grain yield}}{\text{Total evaporation}}$
(D) $\frac{\text{Stomatal conductance}}{\text{Leafarea}}$

2004

103. In Duncan's model, maximizing crop yield through canopy architecture assumes that:
(A) Only the top leaf layer should intercept light
(B) Lower leaves should have a higher specific leaf area
(C) Light is distributed as uniformly as possible over all leaf surfaces
(D) All leaves must be completely horizontal

2019

104. Which metric best captures the physiological advantage of a crop variety that stays green longer during grain filling?
(A) Relative Growth Rate
(B) Specific Leaf Area
(C) Harvest Index
(D) Leaf Area Duration

2018

105. Net Assimilation Rate (NAR) is usually expressed in which units?
(A) $g \cdot m^{-2} \cdot day^{-1}$
(B) $g \cdot g^{-1} \cdot day^{-1}$
(C) $m^2 \cdot g^{-1}$
(D) $kg \cdot ha^{-1}$

2016

106. Low Specific Leaf Area (SLA) is generally an indicator of leaves that are:
(A) Thick and structurally dense
(B) Thin and large
(C) Lacking in mesophyll tissue
(D) Senescent

2015

107. Biological yield in modern high-yielding semi-dwarf wheat varieties compared to traditional tall varieties is typically:
(A) Considerably lower under standard conditions
(B) Entirely independent of chemical fertilizer use
(C) Considerably higher across varied environments
(D) Similar with a much higher harvest index

2003

108. Yield structure analysis partitions total crop yield into numerical components. Which is the most plastic (variable) component in response to environment?
(A) Number of grains per spikelet
(B) Test weight
(C) Floral organ symmetry
(D) Number of productive tillers/branches per

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unit area

2002

109. Which concept defines the physical volume and cell number of an organ designated for assimilate storage?
(A) Source capacity
(B) Phloem unloading rate
(C) Sink size
(D) Sink activity

2001

110. Consider the following statements concerning canopy leaf orientation:
I. Erectophile canopies have predominantly vertical leaves.
II. Planophile canopies have predominantly horizontal leaves.
III. Planophile canopies are optimal for extremely high LAI conditions.
IV. Erectophile canopies allow higher light penetration deeper into the canopy.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) I, III and IV
(C) II and III
(D) I and II

2004

111. If the light extinction coefficient (k) approaches 1.0, the canopy architecture is likely:
(A) Highly erect
(B) Composed of transparent leaves
(C) Completely defoliated
(D) Highly horizontal (planophile)

2005

112. The concept of Critical LAI is physiologically defined as the LAI at which:
(A) 50% of incident PAR is intercepted
(B) 95% of incident PAR is intercepted
(C) The crop begins to senesce
(D) Transpiration exceeds water uptake

2023

113. Stomatal conductance under high VPD is regulated by the accumulation of which phytohormone?
(A) Auxin
(B) Gibberellic Acid
(C) Abscisic Acid (ABA)
(D) Cytokinin

2025

114. Long-day plants undergo floral initiation when:
(A) The dark period is longer than a critical length
(B) Exposed to continuous low temperatures
(C) Placed in absolute darkness
(D) The dark period is shorter than a critical length

2019

115. A base temperature (T_b) used in thermal time calculation represents the temperature:
(A) At which developmental rate is zero
(B) At which developmental rate is maximal
(C) Below which freezing damage occurs
(D) At which harvest maturity is achieved

2004

116. Heliothermal Units (HTU) provide a more accurate prediction of crop maturity than GDD in environments with:
(A) Constant clear skies
(B) Highly variable cloud cover and sunshine duration
(C) Uniform daily temperatures
(D) Zero diurnal temperature range

2001

117. Donald's ideotype concept fundamentally shifted crop breeding from selecting for individual plant performance to:
(A) Maximum weed competitiveness
(B) Community/population performance
(C) Highest specific leaf area
(D) Lowest harvest index

NODIA

2004

118. Which structural feature in the "New Plant Type" rice was designed to prevent lodging?
(A) Thick, sturdy culms and reduced height
(B) Deep, narrow root system
(C) Extensive panicle branching
(D) Horizontal leaf display

2002

119. A high canopy temperature depression (CTD) value in wheat under hot environments indicates:
(A) Stomatal closure
(B) Root death
(C) Effective transpirational cooling and open stomata
(D) Severe water deficit

2002

120. Consider the following statements regarding the use of an IRGA:
I. It requires a flow meter to measure air flow rate.
II. It assumes CO_2 absorbs infrared light

efficiently.
III. It compares the CO_2 mole fraction of reference air and sample air.
IV. Humidity must be measured or controlled to accurately compute gas exchange.
V. It can calculate internal leaf CO_2 concentration (Ci).
Which of the above statement(s) is/are correct?
(A) I, III, IV, and V
(B) II only
(C) I and II
(D) II, III, and IV

2015

121. Ceptometers estimate Leaf Area Index indirectly by applying which mathematical principle?
(A) Fick's Law of Diffusion
(B) Beer-Lambert Law
(C) Poiseuille's Equation
(D) The Michaelis-Menten kinetics

2017

122. Which instrument is used to measure the water potential of a leaf by applying external pressure to a severed petiole?
(A) Pressure chamber (Scholander bomb)
(B) Psychrometer
(C) Porometer
(D) Lysimeter

2001

123. The historical significance of crop physiology in the Green Revolution was largely based on improving:
(A) Total biological yield alone
(B) Seed dormancy
(C) Root nodulation in cereals
(D) Harvest index via semi-dwarf genes

2024

124. In maize, physiological stress during the silking stage predominantly reduces yield by causing:
(A) Tassel abortion
(B) Accelerated leaf senescence
(C) Inhibition of primary root elongation
(D) Kernel abortion and reduced grain set

2017

125. The energetic requirement to fix one molecule of N2 via the nitrogenase enzyme complex in pulses is approximately:
(A) 2 ATP
(B) 4 ATP
(C) 16 ATP
(D) 36 ATP

2025

126. Groundnut (Arachis hypogaea) is unique among major oilseeds due to which physiological trait?
(A) Aerial pod formation
(B) Geocarpy (subterranean fructification)
(C) Absence of root nodules
(D) Total reliance on wind pollination

2001

127. In Passioura's framework, which strategy improves Transpiration Efficiency (TE) in a water-limited environment?
(A) Increasing stomatal density
(B) Maximizing vegetative biomass
(C) Reducing harvest index
(D) Enhancing photosynthetic capacity per unit of transpired water

2018

128. Duncan's canopy model demonstrates that optimal leaf angle changes with depth. What is the ideal arrangement?
(A) Horizontal leaves at the top, vertical at the bottom
(B) Vertical (erect) leaves at the top, horizontal at the bottom
(C) Vertical leaves throughout the entire canopy
(D) Horizontal leaves throughout the entire canopy

2008

129. Crop Growth Rate (CGR) peaks during which phenological phase of a typical annual crop?
(A) Seedling establishment
(B) Linear phase of vegetative growth and early reproduction
(C) Late grain filling
(D) Physiological maturity

2008

130. The following question consists of two statements—Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): Leaf Area Duration (LAD) is strongly and positively correlated with total biomass production.
Reason (R): LAD integrates the total photosynthetically active surface area over the entire growing season.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

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2025

131. Which of the following defines Specific Leaf Area (SLA)?
(A) Leaf dry weight per unit leaf area
(B) Leaf area per unit leaf dry weight
(C) Leaf area per unit total plant dry weight
(D) Total canopy area per unit ground area

2021

132. The theoretical upper limit of Harvest Index in modern cereal crops is estimated to be approximately:
(A) 0.30 - 0.35
(B) 0.60 - 0.65
(C) 0.85 - 0.90
(D) 1.00

2017

133. Which component of yield structure is most directly influenced by seeding rate and plant population density?
(A) Grain weight
(B) Number of grains per spikelet
(C) Number of plants/tillers per unit area
(D) Nutritional quality of the grain

2015

134. Sink strength regulates the rate of phloem transport primarily by:
(A) Altering xylem water potential
(B) Closing stomata
(C) Inhibiting RuBisCO activity
(D) Maintaining a steep sucrose concentration gradient from source to sink

2024

135. A "droopy" leaf architecture typically results in:
(A) Higher mutual shading and lower optimum LAI
(B) Lower light extinction coefficient
(C) Enhanced deep light penetration
(D) Increased harvest index

2017

136. Photosynthetically Active Radiation (PAR) falls within the wavelength range of:
(A) 200 - 400 nm
(B) 400 - 700 nm
(C) 700 - 1000 nm
(D) 1000 - 2000 nm

2009

137. Which state occurs if a crop's LAI significantly exceeds the optimum LAI?
(A) Canopy photosynthesis continues to increase linearly
(B) Stomata permanently close
(C) Parasitic respiration by lower leaves decreases overall net growth
(D) Roots cease to function

NODIA

2018

138. Which structural feature helps certain crop leaves minimize VPD-induced water stress?
(A) Thick waxy cuticle
(B) Increased stomatal aperture
(C) Thinner mesophyll layers
(D) Increased specific leaf area

2016

139. Phytochrome primarily mediates photoperiodic responses by sensing the ratio of:
(A) Blue to Ultraviolet light
(B) Green to Yellow light
(C) Microwave to Infrared radiation
(D) Red to Far-Red light

2008

140. Match the physiological parameter in List I with its standard mathematical formula in List II:
List I: (Parameter)
P. RGR
Q. NAR
R. SLA
S. CGR
List II: (Formula)
1. $\frac{1}{W} \times \frac{dW}{dt}$
2. $\frac{1}{L} \times \frac{dW}{dt}$
3. $\frac{L}{WL}$
4. $\frac{1}{A} \times \frac{dW}{dt}$

[Where W=dry weight, L=leaf area, WL=leaf dry weight, A=ground area]
(A) P-1, Q-2, R-3, S-4
(B) P-2, Q-1, R-4, S-3
(C) P-1, Q-4, R-3, S-2
(D) P-4, Q-2, R-3, S-1

2013

141. The physiological concept of Thermal Time assumes that:
(A) Photoperiod is the only driver of development
(B) Plant development is driven by the accumulation of daily heat units above a threshold
(C) High temperatures delay flowering exponentially
(D) Growth rates are constant regardless of temperature

2024

142. A crop ideotype designed for high-density planting must necessarily feature:
(A) Spreading and highly branched morphology
(B) Compact morphology with erect leaves
(C) High specific leaf area with horizontal leaves
(D) Extensive lateral root spread

2012

143. Which index measures the ratio of carbon assimilated to water transpired at the leaf level?
(A) Water Use Efficiency (WUE)
(B) Leaf Area Ratio (LAR)
(C) Specific Leaf Weight (SLW)
(D) Harvest Index (HI)

2001

144. In an open gas exchange system (IRGA), the calculation of net assimilation rate is directly derived from:
(A) The pressure difference in the chamber
(B) The difference in CO_2 concentration between inlet and outlet air
(C) The total volume of the leaf chamber
(D) The absolute humidity of the outlet air alone

2018

145. A SPAD meter evaluates the "greenness" of a leaf by:
(A) Measuring light transmittance differences between 650 nm and 940 nm
(B) Chemically extracting chlorophyll
(C) Assessing thermal emission from the leaf
(D) Determining specific leaf area

2003

146. Which fundamental process links source capacity with crop yield?
(A) Transpiration
(B) Assimilate partitioning
(C) Phototropism
(D) Root elongation

2023

147. During early vegetative growth, the primary sink for photoassimilates is the:
(A) Grain
(B) Developing roots and new leaves
(C) Floral primordia
(D) Stem internodes

2021

148. Which factor is the most common constraint limiting yield in indeterminate pulse crops?
(A) Lack of vegetative growth
(B) Excessive overlapping of vegetative and reproductive phases
(C) Insufficient root nodulation at maturity
(D) Immediate senescence of leaves upon flowering

2022

149. The pod-filling stage in soybean is highly sensitive to which environmental stress, causing significant yield loss?
(A) Water deficit (drought)
(B) Soil waterlogging
(C) Low wind speed
(D) Mild nighttime temperatures

2019

150. Select the correct sequence of hierarchy in yield components for cereals, from largest spatial scale to smallest:
(A) Spikes per m^2 → Spikelets per spike → Grains per spikelet → Individual grain weight
(B) Grains per spikelet → Individual grain weight → Spikes per m^2 → Spikelets per spike
(C) Spikelets per spike → Spikes per m^2 → Individual grain weight → Grains per spikelet
(D) Individual grain weight → Grains per spikelet → Spikelets per spike → Spikes per m^2

2018

151. Passioura's equation defines yield fundamentally through the lens of:
(A) Nitrogen utilization
(B) Water capture and use efficiency
(C) Light interception only
(D) Phosphorus partitioning

2010

152. Duncan's mathematical simulation highlighted that high LAI canopies benefit most from:
(A) Horizontal leaves
(B) Highly clumped foliage
(C) Completely shaded lower canopies
(D) Erect leaves

2018

153. A rapid decline in RGR as a plant ages is primarily attributed to:
(A) An increase in the proportion of non-photosynthetic structural biomass
(B) A continuous increase in NAR
(C) The cessation of root growth
(D) Enhanced nitrogen fixation

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2021

154. Which morphological parameter determines the maximum possible light interception capacity of a crop canopy?
(A) Specific leaf weight
(B) Maximum Leaf Area Index
(C) Root-to-shoot ratio
(D) Test weight

2025

155. SLW is typically calculated as:
(A) Leaf area divided by leaf dry weight
(B) Leaf dry weight divided by leaf area
(C) Leaf fresh weight divided by leaf dry weight
(D) Total plant weight divided by leaf area

2015

156. The economic yield of a forage crop is typically equal to:
(A) Its total above-ground biological yield
(B) Its grain yield
(C) Its root biomass
(D) Its harvest index

2008

157. Which component defines the 'test weight' of a cereal crop?
(A) Weight of a single grain
(B) Total grain weight per plant
(C) Weight of grain per square meter
(D) Weight of 1000 grains

2025

158. Sucrose is the preferred transport sugar in the phloem because it is:
(A) A non-reducing sugar and chemically stable
(B) A highly reactive reducing sugar
(C) A large polysaccharide
(D) Easily metabolized during transit

2009

159. The leaf angle that theoretically minimizes the extinction coefficient (k) is:
(A) 0 degrees (horizontal)
(B) 45 degrees
(C) 180 degrees
(D) 90 degrees (vertical)

2016

160. Arrange the following processes of assimilate transport in correct order, then select the matching option:
1. Phloem loading
2. Synthesis of sucrose in mesophyll
3. Phloem unloading at sink
4. Translocation via mass flow

(A) 2, 1, 4, 3
(B) 1, 2, 3, 4
(C) 2, 4, 1, 3
(D) 4, 3, 2, 1

2009

161. A critical LAI value is conceptually identical to:
(A) The LAI where crop growth rate stops increasing
(B) The LAI where crop growth rate becomes negative
(C) The LAI at which the plant dies
(D) The LAI that produces zero economic yield

2007

162. Stomatal closure induced by high VPD directly reduces:
(A) Internal leaf temperature
(B) Intercellular CO_2 concentration (Ci)
(C) Oxygen evolution in roots
(D) Soil evaporation

NODIA

2023

163. The induction of flowering by exposure to cold temperatures is called:
(A) Photoperiodism
(B) Stratification
(C) Thermoperiodicity
(D) Vernalization

2017

164. What happens to the GDD accumulation if the mean daily temperature falls below the base temperature (Tb)?
(A) It is recorded as zero for that day
(B) It accumulates as a negative value
(C) It resets the cumulative GDD to zero
(D) It triggers immediate senescence

2001

165. The calculation of Photothermal Units (PTU) is given by:
(A) GDD / Day Length
(B) GDD $\times$ Night Length
(C) GDD + Day Length
(D) GDD $\times$ Day Length

2017

166. A defining feature of Donald's ideotype is the elimination of:
(A) Competitive features that reduce community yield
(B) The main stem
(C) High harvest index traits
(D) Drought tolerance mechanisms

2022

167. Which of the following is an effective physiological selection index for heat tolerance in wheat?
(A) Low canopy temperature depression
(B) High membrane thermostability
(C) Early loss of chlorophyll
(D) High rate of flower abscission

2021

168. To compute photosynthesis accurately, an IRGA system must measure air flow rate, differential CO_2 concentration, and:
(A) Soil pH
(B) Root respiration
(C) Total canopy weight
(D) Leaf area enclosed in the chamber

2025

169. What is a primary limitation of using a Ceptometer for estimating LAI?
(A) It cannot measure PAR
(B) It destructively samples the leaves it measures
(C) It only functions in absolute darkness
(D) It requires assumptions about canopy leaf angle distribution

2007

170. Which mechanism allows wheat to compensate for a low plant population density?
(A) Increased test weight
(B) Decreased spikelet number
(C) Reduced leaf area
(D) Profuse tillering

2019

171. The "stay-green" trait in cereals is highly valued because it:
(A) Prevents grain formation
(B) Maintains active photosynthesis during the grain-filling period
(C) Increases vegetative lodging
(D) Decreases final harvest index

2011

172. In pulse physiology, indeterminate varieties are characterized by:
(A) Simultaneous vegetative growth and flowering
(B) Complete cessation of leaf growth upon the first flower
(C) Absolute day-neutrality
(D) Lack of root nodules

2003

173. What is a common physiological effect of low irradiance (shading) on oilseed leaves?
(A) Decreased Specific Leaf Area (SLA)
(B) Increased Specific Leaf Area (SLA)
(C) Increased Specific Leaf Weight (SLW)
(D) Increased root-to-shoot ratio

2012

174. The "Harvest Index" formula ($HI = \frac{YE}{YB}$) was prominently utilized to breed varieties during which agricultural era?
(A) The Dust Bowl
(B) The Green Revolution
(C) The Industrial Revolution
(D) The Neolithic Revolution

2008

175. According to Duncan's simulation, canopy architecture only significantly limits photosynthesis when:
(A) LAI is highly optimal or supra-optimal (dense canopy)
(B) LAI is very low
(C) Plants are isolated
(D) The extinction coefficient is zero

2010

176. Which condition characterizes the calculation of CGR?
(A) It measures single leaf efficiency only
(B) It integrates the performance of the entire community over ground area
(C) It ignores absolute dry weight changes
(D) It is determined strictly by grain weight

2004

177. A crop with a high NAR but very low LAI will typically have:
(A) A massive biological yield
(B) Severe mutual shading
(C) The highest possible harvest index
(D) A low overall Crop Growth Rate (CGR)

2008

178. Specific Leaf Area (SLA) is inversely proportional to:
(A) Leaf thickness and density
(B) Leaf Area Ratio
(C) Soil moisture
(D) Intercellular space volume

2003

179. A crop is considered sink-limited if:
(A) Artificial removal of leaves decreases yield
(B) Artificial reduction in grain number does not alter remaining grain weight
(C) Artificial removal of 50% of the grains leads to larger remaining grains

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(D) Shading decreases grain yield

2018

180. The following question consists of two statements—Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.

Assertion (A): Cultivated rice (Oryza sativa) has a highly efficient physiological mechanism for internal oxygen transport.

Reason (R): Rice possesses extensive aerenchyma tissue in its stems and roots.

(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2007

181. Yield components in crop architecture are generally established in a chronological sequence. For wheat, which is determined last?
(A) Tiller number
(B) Grain weight
(C) Spikelet number
(D) Floret fertility

2013

182. Apoplastic phloem unloading relies heavily on which biochemical mechanism to maintain a gradient?
(A) Symporters and cell wall invertase
(B) Simple diffusion through plasmodesmata
(C) Xylem aspiration
(D) Capillary action

2008

183. Which morphological trait is characteristic of a planophile canopy?
(A) Upright leaves
(B) Drooping, horizontal leaves
(C) Deep root systems
(D) Absence of flag leaves

2003

184. In the Beer-Lambert law ($I = I_0 e^{-k \times LAI}$), I_0 represents:
(A) Transmitted light at the bottom of the canopy
(B) The extinction coefficient
(C) Reflected light
(D) Light intensity at the top of the canopy

2004

185. If a crop canopy has a leaf area index (LAI) of 3 and an extinction coefficient (k) of 0.7, the fraction of light transmitted to the ground is approximately:
(A) $e^{-3.0}$
(B) $e^{\{-2.1\}}$
(C) $e^{-0.7}$
(D) $e^{-0.21}$

2009

186. Which physiological state minimizes the negative impact of high Vapor Pressure Deficit on crop yield?
(A) High stomatal sensitivity to ABA
(B) High root hydraulic conductivity
(C) Low leaf water potential threshold for stomatal closure
(D) Absence of a waxy cuticle

2004

187. In an obligate short-day plant, an interruption of the long dark period by a brief flash of red light will:
(A) Prevent flowering
(B) Promote flowering
(C) Induce tuberization
(D) Cause immediate leaf senescence

2005

188. Which formula properly calculates the thermal time accumulated over n days?
(A) $\sum(T_{mean} - T_{base})$
(B) $\sum(T_{\max} \times T_{\min})$
(C) $\sum(T_{base} - T_{mean})$
(D) $\sum \frac{T_{mean}}{T_{base}}$

2002

189. A Heliothermal Unit (HTU) incorporates hours of bright sunshine. This accounts for variations in:
(A) Actual solar radiation received for photosynthesis
(B) Soil nutrient availability
(C) Nighttime respiration losses
(D) Day length sensing by phytochrome

2016

190. Match the physiological index in List I with its primary utility in plant breeding in List II:
List I: (Physiological Index)
P. Carbon Isotope Discrimination ($\Delta^{13}C$)
Q. Canopy Temperature Depression (CTD)
R. Chlorophyll Fluorescence (Fv/Fm)
S. Specific Leaf Area (SLA)
List II: (Primary Utility)

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1. Transpiration efficiency / Water Use Efficiency
2. Root depth and transpirational cooling
3. Photosystem II quantum efficiency
4. Leaf structural investment

(A) P-1, Q-2, R-3, S-4
(B) P-2, Q-1, R-3, S-4
(C) P-3, Q-4, R-1, S-2
(D) P-1, Q-3, R-2, S-4

2025

191. Donald's ideal wheat plant type minimized tillering to reduce:
(A) Intra-plant competition for assimilates
(B) Grain weight
(C) Harvest index
(D) Light penetration

2011

192. Physiological breeding differs from empirical breeding by selecting directly for:
(A) Final grain yield only
(B) Underlying traits and mechanisms that drive yield
(C) Visual aesthetic traits
(D) Purely random mutations

2012

193. The primary limitation of using Porometers in field environments is:
(A) High sensitivity to rapid fluctuations in ambient humidity and wind
(B) Their inability to measure leaf temperature
(C) They are highly destructive
(D) They only function at night

2005

194. Which principle underlies the function of a Leaf Area Meter?
(A) Chemical extraction of leaf pigments
(B) Assessment of water displacement in a closed chamber
(C) Infrared thermal imaging
(D) Measurement of intercepted light as leaves pass over a scanner

2013

195. Which historical figure is primarily credited with mathematically formalizing the concepts of RGR, NAR, and LAR?
(A) Passioura
(B) Donald
(C) Gregory
(D) Duncan

2011

196. The "Source" in crop source-sink dynamics is most precisely defined as:
(A) Any organ that imports photoassimilates
(B) Any organ that is a net exporter of photoassimilates
(C) Only the apical meristem
(D) Only the root nodules

2005

197. Which organ serves as a transitional sink-to-source during the maturation of a cereal leaf?
(A) Root tip
(B) Developing grain
(C) Flower petal
(D) Flag leaf

2001

198. The high flower shedding rate in pigeonpea is primarily considered a physiological mechanism for:
(A) Adjusting sink load to match limited source capacity
(B) Increasing total biological yield
(C) Increasing vulnerability to pests
(D) Enhancing root nodulation

2008

199. Mustard (Brassica juncea) leaves contribute to total plant photosynthesis up to flowering, after which the primary photosynthetic organ becomes the:
(A) Tap root
(B) Stem and siliqua wall
(C) Petals
(D) Secondary branches

NODIA

2004

200. Passioura suggested that increasing harvest index in dryland crops could be achieved by:
(A) Increasing early vegetative vigor to use all water rapidly
(B) Reducing excessive early vegetative growth to conserve water for grain filling
(C) Completely eliminating root systems
(D) Increasing plant height to maximum potential

2006

201. Which leaf architecture trait increases the efficiency of scattered (diffuse) light interception?
(A) Perfectly vertical orientation
(B) Spherical or varied leaf angle distribution
(C) Highly clumped horizontal leaves
(D) Loss of all lower leaves

2008

202. The decline in NAR observed in dense stands is fundamentally driven by:
(A) Nutrient toxicity
(B) Mutual shading causing lower leaves to respire more than they photosynthesize
(C) Enhanced stomatal conductance
(D) Increased photoperiod length

2025

203. LAD is calculated mathematically by integrating LAI over:
(A) Solar radiation
(B) Time
(C) Temperature
(D) Ground area

2022

204. High Specific Leaf Weight (SLW) in crop species generally correlates with:
(A) Lower photosynthetic rates per unit leaf area
(B) Higher photosynthetic rates per unit leaf area
(C) Thinner leaves with sparse mesophyll
(D) Rapid leaf senescence

2007

205. The formula

$$HI = \frac{\text{Economic Yield}}{\text{Biological Yield}} \times 100$$

Assumes that biological yield encompasses:
(A) Above-ground dry matter only
(B) Total plant dry matter including roots
(C) Only the vegetative dry matter
(D) The fresh weight of the entire plant

2021

206. A wheat crop with fewer spikes per square meter can compensate and maintain yield by:
(A) Reducing grains per spike
(B) Increasing grains per spike and individual grain weight
(C) Increasing plant height
(D) Accelerating leaf senescence

2007

207. Which hormone plays a critical role in establishing sink strength in developing seeds by promoting cell division?
(A) Ethylene
(B) Cytokinin
(C) Abscisic Acid
(D) Salicylic Acid

2016

208. An Erectophile canopy is advantageous for high-yielding varieties because it:
(A) Maximizes shading of weeds at early stages
(B) Allows PAR to illuminate a greater total leaf area volume
(C) Reduces the optimal LAI
(D) Prevents all light from reaching the soil

2003

209. If the extinction coefficient (k) is high, the canopy achieves critical LAI at a:
(A) Lower numerical LAI value
(B) Higher numerical LAI value
(C) Value of exactly 1.0
(D) Negative value

2021

210. Optimum LAI is mathematically distinct from Critical LAI in that:
(A) Optimum LAI maximizes Crop Growth Rate
(B) Optimum LAI maximizes Net Assimilation Rate
(C) Optimum LAI is where 95% of light is intercepted
(D) Optimum LAI occurs at seedling emergence

2010

211. High VPD atmospheric conditions drive up the transpiration rate up to a certain point, after which:
(A) The plant roots undergo hydraulic rupture
(B) Stomatal conductance decreases to restrict further water loss
(C) Photosynthesis becomes completely independent of water status
(D) The leaves permanently wilt without any regulation

2014

212. Photoperiodic sensitivity in crops like rice restricts their wide geographical adaptation primarily because:
(A) They require specific day lengths to initiate flowering
(B) They are intolerant to high rainfall
(C) They need excessive vernalization
(D) They possess low harvest indices

2006

213. Base temperature (T_b) varies among crops. Which crop typically has the highest T_b?
(A) Wheat
(B) Barley
(C) Maize
(D) Oat

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2017

214. The base temperature (T_b) for rice (Oryza sativa) is typically considered to be:
(A) 0 °C
(B) 5 °C
(C) 10 °C
(D) 15 °C

2015

215. The 'Ideotype' concept revolutionized breeding by moving away from 'defect elimination' to:
(A) Designing a theoretical plant model optimized for a specific environment
(B) Random mass selection
(C) Selecting exclusively for disease resistance
(D) Breeding for maximum biological yield regardless of economic yield

2023

216. Which trait is a fundamental component of the IRRI New Plant Type (NPT) for tropical rice?
(A) High tillering capacity (over 20 tillers)
(B) Low tillering capacity (3-4 heavy panicles)
(C) Tall stature to compete with weeds
(D) Drooping leaves

2019

217. Carbon Isotope Discrimination ($|\Delta^{13}C$) is used as a surrogate measurement for:
(A) Root depth
(B) Transpiration efficiency
(C) Nighttime respiration rate
(D) Nodule nitrogen fixation

2024

218. An open-system IRGA prevents internal humidity buildup by:
(A) Continuously flowing a known stream of air through the leaf chamber
(B) Using a chemical desiccant to destroy the leaf
(C) Sealing the chamber completely and letting pressure build
(D) Chilling the leaf to freezing temperatures

2006

219. A SPAD meter is widely utilized in precision agriculture primarily to manage the application of:
(A) Phosphorus
(B) Potassium
(C) Nitrogen
(D) Calcium

2023

220. Which instrument is essential for quantifying stomatal resistance rapidly in the field?
(A) Bomb calorimeter
(B) Porometer
(C) Soil moisture probe
(D) Optical leaf area meter

2021

221. Source limitation during the grain-filling period of wheat is most likely exacerbated by:
(A) Cloudy weather and foliar diseases
(B) Adequate soil moisture and high irradiance
(C) Complete removal of competing tillers
(D) Cold nighttime temperatures

2022

222. What physiological trade-off exists in modern high-yielding indeterminate pulses?
(A) High flower production leads to low abscission rates
(B) Extended vegetative growth competes directly with pod filling for assimilates
(C) Root nodulation completely stops photosynthesis
(D) High harvest index causes immediate root death

2009

223. Passioura's framework highlights that Yield is mathematically the product of Water Transpired, Transpiration Efficiency, and HI. Which component is most genetically fixed and hardest to increase?
(A) Total Water Transpired
(B) Transpiration Efficiency
(C) Harvest Index
(D) Leaf Area Index

NODIA

2007

224. Which condition mathematically occurs when CGR is divided by LAI?
(A) Specific Leaf Area
(B) Leaf Area Duration
(C) Net Assimilation Rate
(D) Relative Growth Rate

2012

225. What happens to the physiological function of lower canopy leaves when LAI surpasses the critical LAI?
(A) They become net consumers of assimilates (parasitic)
(B) They switch to C4 photosynthesis
(C) They increase their specific leaf weight
(D) They close their stomata permanently but maintain high photosynthesis

2002

226. What causes the characteristic structural rigidity in high SLW leaves?
(A) High water content and expanded vacuoles
(B) Increased layers of palisade mesophyll and dense cellular packing
(C) High levels of intercellular air spaces
(D) Absence of vascular bundles

2013

227. In assimilate partitioning, the phenomenon where a strong sink dictates the directional flow of phloem sap is termed:
(A) Sink dominance
(B) Source restriction
(C) Apoplastic block
(D) Hydraulic lift

2010

228. Which environmental parameter is the absolute primary driver calculating Growing Degree Days?
(A) Incident solar radiation
(B) Ambient air temperature
(C) Soil moisture tension
(D) Vapor pressure deficit

2017

229. Donald's Ideotype emphasizes "weak competitors" as ideal crop plants because:
(A) They exhibit poor yield performance when grown in a monoculture
(B) They prioritize community harvest index over individual plant size
(C) They produce excessive canopy shade that affects the adjacent rows
(D) They develop massive root systems that drain shared soil resources

2017

230. The light intensity at which the rate of photosynthetic CO_2 uptake exactly equals the rate of respiratory CO_2 release is the:
(A) Light saturation point
(B) Light compensation point
(C) Quantum yield point
(D) Critical leaf area index

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ANSWERS

1. (B) Briggs and Shantz ratio
The relationship between dry matter accumulation and water transpired was pioneered by researchers during the early twentieth century. This ratio quantifies the amount of water used by a crop to produce a specific unit of dry weight. It established the foundational understanding of water use efficiency in agriculture, linking physiological transpiration processes directly to biomass production.

2. (A) Meiosis and heading
Spikelet fertility in rice is most vulnerable to environmental stresses during reproductive stages. The period around meiosis and heading represents a critical physiological window where disruptions can lead to high sterility rates. Temperature fluctuations or water deficits at this time directly impair pollen development and successful fertilization, significantly reducing final grain yield and total productivity in affected crops.

3. (C) High harvest index is common in traditional landraces
Traditional landraces of major pulses typically exhibit low harvest indices because they prioritize vegetative biomass for survival in harsh conditions. Physiological constraints like indeterminate growth and flower abscission further limit their efficiency. Unlike modern varieties bred for productivity, these plants allocate more resources to stems and leaves, leading to a relatively lower proportion of grain weight in maturity.

4. (D) Pod development
In groundnut growth, the primary sink during later reproductive phases shifts towards developing pods. After fertilization, the elongation of the peg pushes the embryo into the soil where pods expand. These organs actively accumulate photoassimilates mobilized from source leaves. This stage is crucial because the sink strength of the pods determines the final kernel size and total crop yield.

NODIA

5. (B) I and III
Passioura's equation defines grain yield as the product of total transpiration, transpiration efficiency, and harvest index. While the first and third statements are accurate, the second is incorrect because transpiration efficiency is fundamentally influenced by vapor pressure deficit. Understanding these components helps agronomists analyze how water availability and partitioning efficiency contribute to the overall productivity of field crops.

6. (B) Canopy photosynthesis based on leaf angle and LAI values
Duncan's crop growth model focuses on mathematical simulation of canopy photosynthesis. It integrates structural parameters such as leaf area index and specific leaf angles to estimate light interception throughout canopy layers. By calculating how light penetrates different architectures, the model predicts cumulative carbon assimilation, providing insights into how plant geometry influences the growth and productivity of the entire community.

7. (D) The plant material increase per unit material per unit time
Relative Growth Rate provides a measure of the efficiency of a plant in producing new biomass relative to existing material. It is calculated by dividing absolute growth rate by the total dry weight at any given time. This parameter allows for comparison between plants of different sizes, reflecting their inherent physiological capacity for expansion, carbon sequestration, and overall development.

8. (A) Leaf Area Duration
Leaf Area Duration represents the integral of the leaf area index over a specific period. It quantifies the total size and persistence of the photosynthetic system throughout the growing season. A higher duration generally correlates with increased total dry matter production because the crop maintains a functional green canopy for a longer period, facilitating consistent capture of solar radiation.

9. (C) Photosynthetic capacity per unit leaf area
Specific Leaf Weight is a measure of leaf thickness and cellular density. Higher values often indicate more layers of palisade mesophyll and higher concentrations of chlorophyll and enzymes like RuBisCO per unit area. Consequently, leaves with greater weight per area typically exhibit higher maximum photosynthetic rates. This trait is often targeted in breeding programs to improve leaf-level physiological efficiency.

10. (A) Both A and R are true and R is the correct explanation of A.
Harvest Index is defined as the ratio of economic yield to the total biological yield produced by a crop. Since the economic part is a subset of the entire plant biomass, the ratio cannot mathematically exceed unity. This index reflects the efficiency of a plant in partitioning its accumulated dry matter into harvested parts like grains, tubers, or fibers.

11. (D) Grain test weight
In wheat, yield components like tiller number and grain number per spike are highly plastic and can compensate significantly when plant density is low. However, individual grain test weight is often the least variable component. While other traits adjust to available resources or space, the density and size of individual kernels tend to remain relatively stable across different canopy structures.

12. (B) Sucrose
Sucrose is the primary carbohydrate transported through phloem in the majority of crop plants. Its non-reducing nature makes it chemically stable for long-distance translocation from source leaves to various sinks. This sugar is easily loaded into sieve tubes and efficiently unloaded at metabolic sites, serving as the fundamental energy substrate for growth and storage across the entire plant.

13. (C) Improved penetration of light into the lower canopy
Vertical leaf orientation is a desirable trait in modern crop varieties intended for high-density planting. Erect leaves minimize the shading of lower layers by allowing sunlight to penetrate deeper into the canopy. This ensures that a larger proportion of total leaf area remains above the light compensation point, thereby increasing net photosynthetic output and overall biological productivity of the stand.

14. (D) Deeper light penetration into the canopy
The light extinction coefficient in the Beer-Lambert law describes how rapidly solar radiation is attenuated as it passes through crop layers. A lower coefficient value indicates that leaves are oriented more vertically, which facilitates deeper light penetration. This architectural arrangement is more efficient for dense canopies because it prevents lower leaves from falling into a state of parasitic respiration.

15. (A) I, II, and III
Optimum Leaf Area Index is defined as the point where crop growth rate is at its maximum. Critical Leaf Area Index is reached when approximately ninety-five percent of incident light is intercepted by the canopy. As total leaf area increases, overall plant respiration also rises. However, optimum index is usually lower than critical index in most field crops.

16. (B) Stomatal closure
An increase in Vapor Pressure Deficit reflects a greater difference between moisture inside the leaf and surrounding air. To prevent excessive water loss and dehydration, plants typically respond by closing their stomata. This physiological mechanism reduces transpiration but simultaneously restricts the entry of carbon dioxide, which can lead to a decrease in the rate of photosynthesis and overall productivity.

17. (B) Photothermal response
The transition from vegetative to reproductive growth in many crops is regulated by the interaction of day length and temperature. This combined influence is known as the photothermal response. It ensures that plants flower at appropriate times of year to maximize reproductive success. Scientists use this concept to predict phenological stages and maturity dates based on cumulative environmental data.

18. (A) Mean daily temperature
Growing Degree Days are a thermal measure used to track the accumulation of heat throughout the growing season. They are calculated by subtracting a crop-specific base temperature from the mean daily temperature. This method accounts for the physiological fact that plant development occurs only when temperatures

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exceed a certain threshold, providing a more accurate developmental timeline than calendar days.

19. (C) Day length
Photothermal Units are a physiological metric that combines thermal time with photoperiod information. They are calculated by multiplying accumulated daily thermal units by the actual day length in hours. This integration is particularly useful for modeling the development of photoperiod-sensitive crops, as it accounts for both temperature-driven metabolic rates and light-driven signals for floral initiation and maturation.

20. (A) P-2, Q-1, R-4, S-3
Donald's wheat ideotype features a single uniculm stem with erect leaves. New Plant Type rice is characterized by low tillering and heavy panicles to maximize efficiency. Groundnut ideotypes often focus on a compact canopy with sequential branching patterns. Meanwhile, cotton ideotypes are designed with short internodes and zero monopodia to optimize allocation of resources towards the developing bolls.

21. (C) High stomatal conductance under stress
When designing selection indices for drought tolerance, traits that conserve water or enhance capture are prioritized. High osmotic adjustment, deep root systems, and improved water use efficiency are beneficial for survival. However, maintaining high stomatal conductance during water stress is generally undesirable because it leads to rapid dehydration. Controlled stomatal closure is often a more effective survival strategy.

22. (B) Carbon dioxide
Infrared Gas Analyzers are fundamental tools in plant physiology for measuring gas exchange. They work by detecting specific absorption of infrared radiation by carbon dioxide molecules. By measuring the difference in gas concentration between air entering and leaving a leaf chamber, researchers can calculate the rate of net photosynthesis. This non-destructive method allows for real-time monitoring of leaf activity.

23. (D) SPAD meter
A SPAD meter is a portable instrument used for non-destructive estimation of chlorophyll levels in leaves. It measures absorbance of red and near-infrared light by leaf tissue to calculate a relative index of greenness. This tool is widely used in nitrogen management, as chlorophyll content is closely related to nitrogen status and the photosynthetic capacity of the plant.

24. (A) The ratio of economic yield to above-ground biological yield
Harvest index represents the proportion of total dry matter produced that is recovered as economic yield. It is typically calculated by dividing the weight of harvested grains or fruits by the total above-ground biomass at maturity. This value indicates the efficiency of the plant in partitioning its resources towards reproductive parts, which was a key focus during Green Revolution breeding.

25. (B) I, II, III and V
Sink strength is determined by the combination of sink size and metabolic activity. It is driven by enzymes like sucrose synthase and invertases that facilitate phloem unloading. Sink size is largely a function of cell number and physical volume. While high sink strength can influence overall plant processes, the provided statements correctly highlight the biochemical and structural determinants of sink capacity.

26. (A) Pollen sterility
High-temperature stress during the anthesis stage in wheat is a major physiological constraint that severely impacts yield. Heat primarily affects development and viability of pollen, leading to increased sterility and reduced grain set. Even if the rest of the plant remains healthy, the failure of fertilization due to sensitive reproductive organs results in significantly fewer kernels and lower productivity.

NODIA

27. (D) Competition between new leaves and developing pods
Indeterminate soybean varieties continue to produce new vegetative nodes and leaves even after flowering has commenced. This overlapping of growth phases creates a physiological conflict where young leaves and developing pods compete for the same pool of available photoassimilates. This internal competition can limit the rate of pod filling and decrease the overall harvest index compared to determinate plant types.

28. (B) Siliqua development
In mustard crops, the siliqua development stage is the most critical period regarding

source limitation. During this phase, demands for carbohydrates to support seed growth and lipid synthesis are at their peak. Any reduction in photosynthetic supply from leaves or green siliqua walls can significantly reduce final oil yield. Maintaining high source capacity is essential during this reproductive window.

29. (C) Reducing stomatal conductance more than assimilation
Transpiration Efficiency is improved when a plant can maximize carbon gain while minimizing water loss. This is most directly achieved by reducing stomatal conductance more than the rate of carbon assimilation. This adjustment increases amount of biomass produced per unit of water transpired. Plants with this trait are better adapted to arid environments where water conservation is vital for productivity.

30. (D) A is false but R is true.
Crop growth rate does not increase continuously until maturity; it typically peaks mid-season and then declines. The reason provided is accurate because in dense stands, lower leaves often fall below the light compensation point due to shading. Consequently, these leaves may consume more energy through respiration than they contribute through photosynthesis, leading to a reduction in overall stand growth.

31. (A) Leaf Area Index (LAI)
Crop Growth Rate is a measure of dry matter accumulated per unit of ground area over time. It is mathematically derived by multiplying Net Assimilation Rate, which reflects leaf efficiency, by Leaf Area Index, which represents leaf surface area per unit ground area. This relationship highlights how both physiological efficiency and total canopy size contribute to the growth of a crop.

32. (B) Mutual shading of leaves
Net Assimilation Rate often decreases as a crop canopy becomes more dense over time. This decline is primarily caused by mutual shading, where upper leaves block sunlight from reaching lower layers. As a result, the average light intensity per unit of leaf area decreases, lowering the photosynthetic efficiency of the entire canopy. This phenomenon limits total carbon gain during later developmental stages.

NODIA

33. (B) Specific Leaf Area
Specific Leaf Area is defined as the ratio of leaf area to leaf dry mass. It serves as an indicator of leaf thickness and structural investment. A higher value suggests that the plant is producing larger, thinner leaves that maximize light interception per unit of biomass. This parameter is useful for understanding how plants allocate carbon resources to optimize photosynthetic surface area.

34. (A) Economic yield and above-ground vegetative biomass
Biological yield is generally defined in agronomy as the total dry weight of the above-ground portion of the plant at maturity. It consists of the sum of economic yield, such as grains or tubers, and the remaining vegetative biomass, including stems and leaves. While roots are technically part of biological yield, they are often excluded in field measurements.

35. (A) Measure grain dry weight → Measure above-ground dry weight → Calculate ratio
To accurately calculate Harvest Index, researchers must first determine the dry weights of the harvested economic part and the total above-ground biomass. This process involves harvesting the crop, drying components in an oven to remove moisture, and weighing them. Finally, the ratio of grain dry weight to total above-ground dry weight is calculated to express partitioning efficiency.

36. (D) Individual grain size and density
Test weight in cereals is a quality and yield component that reflects the weight of a standard volume or number of grains, such as a thousand-grain weight. It is a direct measure of the average size, filling, and density of individual kernels. High test weights indicate successful grain filling and favorable environmental conditions during the reproductive phase, contributing to final harvested yield.

37. (B) Apoplastic active transport
In storage sinks like developing seeds, phloem unloading often occurs through the apoplast. This process involves movement of sugars out of sieve tubes into the extracellular space before they are taken up by sink cells. Active transport mechanisms and enzymes like cell wall invertase are required to maintain a concentration

gradient, ensuring the efficient flow of nutrients into the seed.

38. (C) Horizontal leaves
A high light extinction coefficient is characteristic of crop canopies with horizontal leaf orientations. In these structures, the upper leaf layers intercept most incident solar radiation, creating rapid light attenuation and heavy shading for lower leaves. While horizontal leaves are efficient at low leaf area indices, they often limit total photosynthetic potential in dense stands due to severe mutual shading.

39. (D) Transpiration rate
The Beer-Lambert law is used in crop physiology to model the interception of light by the canopy. Its primary components include incident radiation at the top of the canopy, leaf area index, and the light extinction coefficient. While transpiration is a vital physiological process, it is not a direct variable in this specific equation, which focuses solely on light attenuation.

40. (A) P-2, Q-1, R-4, S-3
Ceptometers are used to measure photosynthetically active radiation and light interception within a canopy. Porometers are designed to assess stomatal conductance by measuring gas diffusion from leaves. SPAD meters provide an estimate of relative chlorophyll content through light transmittance. Finally, leaf area meters are employed for destructive measurements of total surface area of harvested leaves, facilitating growth analysis calculations.

41. (B) Exactly zero
At critical Leaf Area Index, the canopy intercepts about ninety-five percent of incident light. At this point, leaves at the bottom of the canopy receive just enough radiation to balance carbon gains from photosynthesis with losses from respiration. Consequently, their net assimilation rate becomes exactly zero. Any further increase in leaf area would push these lower leaves into a carbon deficit.

42. (B) Reduced CO_2 diffusion into leaves
High Vapor Pressure Deficit creates a stressful environment that triggers stomatal closure to conserve water. This defensive response significantly increases resistance to gas exchange, thereby reducing the diffusion of carbon dioxide into the leaf interior. As carbon dioxide availability decreases within the mesophyll, the rate of photosynthesis is inhibited, which ultimately restricts total biomass accumulation and final harvested crop yield.

43. (A) Longer than a critical duration
Short-day plants are characterized by their requirement for a minimum period of uninterrupted darkness to initiate the transition from vegetative to reproductive growth. Flowering occurs only when the night length exceeds a specific critical threshold. This physiological mechanism ensures that the crop reproduces during seasons with shorter days, aligning its life cycle with favorable environmental conditions for successful seed development.

44. (A) 0-5 °C
Base temperature is the threshold below which physiological development in a plant effectively stops. For temperate crops like wheat, this value is generally accepted to be between zero and five degrees Celsius. This parameter is essential for calculating thermal time or growing degree days, allowing agronomists to predict the timing of phenological stages based on heat unit accumulation.

45. (A) 3, 1, 2, 4
The phenological development of a rice crop follows a specific chronological order. It begins with panicle initiation, followed by the booting stage as the panicle expands within the sheath. Anthesis or flowering occurs next, leading to fertilization of spikelets. Finally, the dough stage marks the period of grain filling and maturation. Correctly identifying these phases is crucial for management.

46. (C) Actual bright sunshine hours
Heliothermal Units are a modification of the growing degree day concept that integrates both temperature and light availability. They are calculated by multiplying daily thermal units by the actual number of bright sunshine hours. This index provides a more comprehensive measure of the energy available for crop growth and development, accounting for variations in cloud cover that thermal-only indices might overlook.

47. (B) A single uniculm stem
Donald's original wheat ideotype proposed a uniculm architecture to minimize intra-plant competition for resources. By eliminating tillers,

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the plant can allocate all its captured energy and nutrients towards a single, large, and highly productive spike. This design aimed to improve harvest index and ensure that every stem in a high-density population contributes effectively to grain yield without competing with itself.

48. (D) Producing fewer but highly productive tillers
The New Plant Type rice was developed to increase yield potential by optimizing plant architecture. A key strategy involved reducing total tiller number and focusing on a few heavy, productive ones. This design minimizes waste of assimilates on unproductive tillers, ensuring more resources are partitioned into large panicles. This approach aims to enhance both biological efficiency and harvested grain index.

49. (A) Crop growth rate at full canopy
A physiological selection index based on crop growth rate at full canopy is used to evaluate efficiency under competitive field conditions. Unlike single plant isolated yield, this metric reflects how a variety performs within a community. It captures the ability of the plant to intercept light and convert it into biomass while competing for shared resources like water and nutrients.

50. (C) I only
Infrared Gas Analyzers operate on the principle that carbon dioxide molecules selectively absorb specific wavelengths of infrared radiation. By measuring this absorption, the instrument can precisely determine gas concentration in an air stream. While it is used to calculate photosynthesis, it does so by detecting CO_2 depletion rather than oxygen changes. Statement I correctly describes the fundamental physical principle.

51. (D) Water vapor diffusion from the leaf
Porometers assess stomatal behavior by measuring the rate of water vapor diffusion from leaf surfaces. This measurement allows researchers to calculate stomatal conductance or resistance. Since stomata control the exchange of both water vapor and carbon dioxide, porometry provides valuable information about a plant's transpiration status and its potential for carbon uptake, reflecting overall leaf health and photosynthetic capacity.

52. (B) Apical meristem differentiation into floral primordia
Transition from vegetative to reproductive growth in cereals is characterized by fundamental changes at the cellular level. The apical meristem, which previously produced leaves and stems, undergoes differentiation to form floral primordia. This physiological shift redirects the plant's developmental program toward production of reproductive structures, marking the beginning of the phase that will ultimately determine grain number and yield potential.

53. (D) Nodule oxygen permeability regulation
Under drought stress, pulse crops must actively manage oxygen levels within root nodules to maintain the sensitive nitrogen-fixing activity of the nitrogenase enzyme. This regulation of oxygen permeability is a metabolically expensive process that consumes significant photoassimilates. By protecting the anaerobic environment inside the nodule, the plant ensures that nitrogen fixation can continue even when other physiological processes are limited.

NODIA

54. (D) Lower absolute seed yield per gram of photosynthate
Lipid synthesis is more energy-intensive than production of carbohydrates or proteins. Because oilseed crops must allocate more carbon and energy to produce a gram of oil than cereal crops use for starch, their theoretical maximum seed yield per unit of photosynthate is lower. This energetic trade-off explains why oilseed crops generally have lower absolute yields compared to high-carbohydrate crops.

55. (C) Harvest Index
Breeding for drought escape typically focuses on early maturity to avoid late-season water deficits. In the context of Passioura's equation, this strategy aims to maximize Harvest Index by ensuring reproductive development occurs while soil moisture is available. By completing its life cycle rapidly, the crop can effectively partition its accumulated biomass into grain before severe stress causes terminal yield failure.

56. (B) Leaf angle distribution
Duncan's canopy model is a mathematical simulation designed to predict photosynthesis based on the structural arrangement of the crop. A primary input for this model is the leaf angle distribution within the canopy. By understanding

how leaves are oriented at different heights, the model can calculate the distribution of light and determine total carbon assimilation of the entire community.

57. (D) Both physiological efficiency and morphological leaf allocation
The formula $RGR = NAR \times LAR$ indicates that the relative growth rate of a plant is the product of its physiological efficiency and its morphological allocation to leaf area. Net Assimilation Rate represents the efficiency of photosynthetic machinery, while Leaf Area Ratio reflects how much biomass is invested in light-capturing surfaces. Both factors are essential for rapid crop development.

58. (A) LAI over time
Leaf Area Duration is a physiological parameter that integrates total leaf area index over the entire growing season or specific growth period. Mathematically, it is represented as the area under the curve when LAI is plotted against time. This metric captures both magnitude of photosynthetic surface and its persistence, providing a strong correlation with total biomass and final yield.

59. (C) Higher concentrations of RuBisCO per unit area
Leaves with high Specific Leaf Weight are characterized by thickness and high cellular density. They typically possess more layers of mesophyll cells and a greater quantity of photosynthetic enzymes, such as RuBisCO, per unit area. This increased concentration of metabolic components allows these leaves to achieve higher maximum photosynthetic rates, making SLW a valuable trait for selecting high potential plants.

60. (A) I, II and III
During vegetative stages, mature leaves act as primary sources of assimilates. The process of phloem loading involves active movement of sugars against a concentration gradient into sieve tubes. In storage sinks like developing seeds, unloading often occurs via the apoplast. These statements correctly describe the fundamental principles of source-sink dynamics and nutrient transport within the plant's vascular system.

61. (D) Pre-anthesis and early post-anthesis
Sink size in cereal grains is largely determined by the number of endosperm cells, which is established during pre-anthesis and early post-anthesis phases. Active cell division during this window sets physical capacity for starch accumulation occurring later. Environmental stresses during this critical period can limit cell numbers, thereby restricting potential grain size and total yield regardless of assimilate availability.

62. (A) Alternate/Spiral
An alternate or spiral phyllotaxy arrangement is highly efficient for minimizing mutual shading among leaves. By staggering positions of leaves along the stem, this pattern ensures sunlight penetrates more effectively through canopy layers. This arrangement maximizes total leaf area receiving direct or filtered light, thereby enhancing overall photosynthetic efficiency and productivity of vertically structured crop stands in the field.

63. (B) Uniform light distribution down to the lower leaves
A canopy with a low light extinction coefficient, such as 0.3, allows for significant light penetration into deeper layers. This architectural characteristic is typically associated with erect leaves, which prevent the upper canopy from capturing all sunlight. As a result, radiation is distributed more uniformly across leaf surfaces, maintaining photosynthetic activity of lower leaves and increasing total crop growth rate.

64. (D) Crop growth rate decreases
Optimum Leaf Area Index is the point where the balance between canopy photosynthesis and total plant respiration is most favorable for growth. When LAI increases beyond this optimum, additional leaves add more to the total respiratory cost than they contribute to carbon gain through photosynthesis, often due to shading. Consequently, the net crop growth rate begins to decline.

65. (D) Closure of stomata to prevent dehydration
Under high Vapor Pressure Deficit, atmospheric demand for moisture increases, leading to potential for water loss. Plants respond by closing stomata to restrict transpiration and maintain internal water balance. This protective mechanism, however, also limits intake of

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carbon dioxide essential for photosynthesis. The resulting reduction in carbon fixation is the primary cause of decreased crop productivity in dry environments.

66. (B) A diurnal fluctuation between day and night temperatures
Thermoperiodicity refers to the physiological requirement of many plants for diurnal fluctuation between daytime and nighttime temperatures. Optimal growth and development often occur when nights are cooler than days. This temperature variation influences metabolic processes, including the balance between daytime photosynthesis and nighttime respiration. Providing the correct thermoperiod is essential for maximizing health and productivity of many greenhouse crops.

67. (D) A linear relationship between growth and temperature above a base
The concept of Growing Degree Days assumes a linear relationship between the rate of plant development and temperature within a certain range. It assumes growth only occurs once temperature rises above a specific base threshold. By summing daily mean temperatures minus this base, researchers create a thermal clock that accurately predicts phenological maturity and timing of key developmental stages.

68. (A) Phenological development and flowering time
Photothermal Units are primarily used to model timing of phenological stages, particularly the transition to flowering. By integrating both thermal time and day length, this index accounts for the two most important environmental factors controlling reproductive development. This dual-factor approach provides much more accurate predictions for photoperiod-sensitive crops than using temperature-based heat units alone across latitudes.

69. (C) Increased lower internode diameter and stem wall thickness
A selection index for lodging resistance focuses on traits that enhance structural integrity of the plant stem. Increasing diameter of lower internodes and thickness of stem walls provides mechanical strength needed to support the canopy and resist wind. These morphological features ensure the plant remains upright, which is essential for maintaining efficient light interception and preventing significant yield losses.

70. (A) I, II, III and V
Ceptometers are non-destructive tools designed to measure photosynthetically active radiation within a canopy. They consist of a linear array of sensors that detect light levels. By applying the Beer-Lambert law to measured fractional light interception, these instruments provide an indirect estimate of leaf area index. They are widely used for rapid, in-situ assessment of crop canopy structure and efficiency.

71. (D) A water vapor analyzer (H_2O IRGA)
To measure transpiration and photosynthesis simultaneously, an Infrared Gas Analyzer system must include a sensor for water vapor alongside the carbon dioxide analyzer. By monitoring changes in both CO_2 and H_2O concentrations as air passes over a leaf, the instrument can calculate both the rate of carbon fixation and water loss. This provides a complete picture of gas exchange.

72. (B) An optical scanner and a conveyor belt
Optical leaf area meters typically utilize a conveyor belt system that moves detached leaves through a scanning area. As leaves pass under an array of light sources and detectors, the instrument measures amount of light blocked, which corresponds to the surface area of the tissue. This destructive method is highly accurate and is standard for determining total leaf area.

73. (C) Total intercepted solar radiation
In an environment where water, nutrients, and pests are not limiting, potential yield of a crop is ultimately determined by the total amount of solar radiation it can intercept and convert into biomass. Light provides the energy for photosynthesis, and the capacity of the canopy to capture this energy throughout the growing season sets the upper boundary for productivity.

NODIA

74. (D) Stem internode reserves
During the grain-filling stage in wheat, if leaves begin to senesce prematurely due to stress, the plant relies on alternative sources of carbohydrates. Stem internodes serve as a critical secondary reservoir, having stored water-soluble carbohydrates during earlier growth. These reserves are mobilized and translocated to developing grains, ensuring that kernel filling

can continue even when leaf photosynthetic output declines.

75. (A) Nitrogenase requires ATP and reducing equivalents
Biological nitrogen fixation is an energy-intensive process because the nitrogenase enzyme requires significant amounts of ATP and reducing power to break the triple bond of N2. This metabolic cost is met by using photoassimilates that would otherwise support growth. Consequently, this high energy demand places a physiological limit on the theoretical maximum yield potential of nitrogen-fixing legumes compared to non-fixing cereals.

76. (A) "Self-destruction" hypothesis where nutrients are heavily mobilized from leaves
The "self-destruction" hypothesis in soybean suggests that during final stages of seed development, pod demand for nutrients exceeds root supply. To meet this demand, the plant mobilizes nutrients from leaves, leading to rapid leaf senescence and a decline in photosynthetic capacity. This physiological trade-off effectively limits the duration of the grain-filling period and final yield in many legume varieties.

77. (D) Save a portion of soil moisture for the reproductive phase
Under water-limited conditions, maximizing Harvest Index requires careful management of available soil moisture. A crop should ideally avoid exhausting all water during the vegetative stage. By saving a portion of soil water for reproductive and grain-filling phases, the plant can maintain photosynthesis and sustain seed development. This strategy ensures accumulated biological yield is effectively converted into harvested economic yield.

78. (A) Erect to allow light penetration
Duncan's model emphasizes that canopy photosynthesis is maximized when upper leaves are oriented more vertically. This erect arrangement allows more sunlight to bypass the top layer and reach lower leaves, which might otherwise be shaded. By distributing light more evenly throughout the entire canopy depth, the plant can maintain a higher overall rate of carbon assimilation and yield potential.

79. (C) Exponentially
A constant Relative Growth Rate implies that plant biomass is increasing in proportion to its current size. This pattern of growth is mathematically described as exponential. In early stages of a crop's life cycle, when resources are abundant and competition is low, plants often exhibit this rapid growth phase where every unit of existing tissue contributes to producing more new material.

80. (A) Both A and R are true and R is the correct explanation of A.
In initial stages of crop growth, there is a linear relationship between Leaf Area Index and Crop Growth Rate as light interception increases. However, once critical LAI is reached, almost all incident light is captured. Beyond this point, any additional leaf area increases mutual shading and respiratory costs without significantly improving photosynthesis, leading to a plateau or decline.

81. (D) The photosynthetic machinery per unit leaf area
Net Assimilation Rate is a physiological measure of net increase in dry matter per unit of leaf area over a specific time. It primarily reflects the average efficiency of photosynthetic machinery across the entire canopy, accounting for both carbon gain through photosynthesis and carbon loss through respiration. It serves as a key indicator of productive capacity of leaves throughout the season.

82. (A) High solar irradiance
Exposure to high solar irradiance during leaf development typically leads to higher Specific Leaf Weight. Leaves grown in full sun are often thicker and have more densely packed mesophyll cells compared to shaded leaves. This structural adaptation increases the concentration of photosynthetic components, allowing the plant to better utilize abundant light energy. High SLW is a common sun-adapted characteristic.

83. (B) Reproductive partitioning
The transition to reproductive phase marks a fundamental shift in how a plant allocates its resources. While the vegetative stage focuses on building biological yield in the form of leaves and stems, reproductive partitioning directs photoassimilates toward development of flowers and seeds. This stage is critical because the efficiency of this partitioning process directly

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84. (D) Number of kernel rows per ear
In maize, yield components are established at different times during development. The number of kernel rows per ear is determined very early in the life cycle, usually during vegetative stages when ear primordia are forming. Other components, such as kernel number and kernel weight, are determined later during flowering and grain filling. Early-season stress can therefore permanently limit row number.

85. (B) The inability of developing organs to utilize available assimilates
Sink limitation occurs when the capacity of developing reproductive organs to store or utilize carbohydrates is lower than the amount of photosynthate being provided by source leaves. In this state, increasing the photosynthetic rate or leaf area will not lead to higher yields because "sinks" are already at their maximum capacity. This suggests grain number or size is the bottleneck.

86. (B) Decrease the effective leaf area to reduce transpiration
Under water deficit conditions, many rice varieties exhibit leaf rolling as a drought-avoidance mechanism. By rolling leaves, plants reduce total surface area exposed to the atmosphere and direct solar radiation. This physical change increases boundary layer resistance and lowers the transpiration rate, helping the plant conserve internal moisture and maintain better water status until favorable conditions return or water becomes available.

87. (D) Exponential
The Beer-Lambert law describes attenuation of light as it passes through a crop canopy using an exponential decay function. This means each successive layer of leaf area intercepts a constant fraction of light reaching it. Consequently, light intensity decreases rapidly from the top of the canopy to the bottom, where only a small percentage of incident radiation remains available for photosynthesis.

88. (A) Leaf angle and canopy architecture
Optimum Leaf Area Index is not a fixed value but varies significantly depending on the specific architecture of the crop. Factors like leaf angle, phyllotaxy, and leaf shape determine how light is distributed within the canopy. Varieties with more erect leaves can support a higher optimum LAI because they allow better light penetration, whereas varieties with horizontal leaves reach optimum at lower values.

89. (C) Driving a faster rate of water loss per unit of CO_2 gained
Elevated Vapor Pressure Deficit increases the driving force for transpiration, causing water to exit the leaf more rapidly through stomata. Even if the rate of carbon dioxide uptake remains the same, the increased water loss per unit of carbon gained results in a significant reduction in transpiration efficiency. This makes high VPD environments particularly challenging as plants must expend more water.

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90. (A) P-1, Q-2, R-3, S-4
Wheat is a classic example of a long-day plant requiring shorter nights to flower. Soybean is categorized as a short-day plant, needing a specific period of darkness to initiate reproduction. Tomatoes are generally day-neutral, meaning flowering is independent of day length. Sugarcane exhibits an intermediate-day response, where flowering is triggered by a relatively narrow range of photoperiods, illustrating diverse light sensing.

91. (D) Occurs only after a prolonged period of cold
Vernalization is a physiological requirement in certain winter crops, such as winter wheat, where exposure to a prolonged period of low temperature is necessary to induce flowering. This mechanism ensures the plant does not enter the vulnerable reproductive stage during winter. Instead, the "cold memory" allows the plant to flower only when favorable spring conditions arrive, ensuring better survival and yield.

92. (A) $\frac{T_{\max} + T_{\min}}{2} - T_{base}$
The standard formula for calculating daily Growing Degree Days involves taking the average of the daily maximum and minimum temperatures and then subtracting the crop-specific base temperature. If the result is less than zero, the value for that day is recorded as zero. This simple index helps agronomists estimate cumulative heat units, allowing for better prediction of crop growth stages.

vegetative and reproductive growth phases. Because these plants continue to produce new leaves and stems after flowering has begun, there is constant internal competition for assimilates. This conflict often limits resources available for pod development and seed filling, leading to high flower abscission and an overall reduction in yield.

149. (A) Water deficit (drought)
The pod-filling stage in soybean is highly vulnerable to water deficit or drought stress. During this period, the plant requires a steady supply of moisture to maintain photosynthesis and transport nutrients to the developing seeds. Severe water stress at this time can cause premature leaf senescence, reduce the rate of dry matter accumulation in the pods, and lead to significantly smaller seeds.

150. (A) Spikes per m^2 → Spikelets per spike → Grains per spikelet → Individual grain weight
The yield of a cereal crop is the product of several components established in a specific hierarchy and chronological order. It starts with number of spikes per square meter, followed by number of spikelets per spike. Next is number of grains per spikelet, and finally, the weight of each individual grain. Understanding this sequence helps agronomists identify when stresses affect yield.

151. (B) Water capture and use efficiency
Passioura's yield equation provides a framework for analyzing crop productivity in terms of water resources. It defines yield as the product of total water transpired, the efficiency with which water is converted into biomass, and the proportion of biomass harvested as economic yield. This approach highlights that in water-limited environments, improving any of these three physiological components leads to higher grain yields.

152. (D) Erect leaves
Duncan's mathematical simulations demonstrated that for high-density crop canopies with a large leaf area index, an erect leaf architecture is most beneficial. Vertical leaves at the top of the canopy allow more sunlight to penetrate to deeper layers, preventing lower leaves from being shaded below their compensation point. This balanced light distribution ensures the entire canopy remains photosynthetically productive and efficient.

153. (A) An increase in the proportion of non-photosynthetic structural biomass
The decline in Relative Growth Rate as a plant matures is a natural physiological process. It is primarily caused by an increase in the proportion of non-photosynthetic structural and storage tissues, such as thick stems and seeds, relative to active leaf area. As the plant builds more "dead weight" that respires but does not photosynthesize, growth rate relative to total mass decreases.

154. (B) Maximum Leaf Area Index
The maximum Leaf Area Index achieved by a crop is the primary morphological parameter determining total light interception capacity. LAI represents the amount of leaf surface area available to capture solar radiation per unit of ground area. A higher LAI allows the crop to intercept a greater fraction of incident light, setting the boundary for total carbon fixed through canopy photosynthesis.

155. (B) Leaf dry weight divided by leaf area
Specific Leaf Weight is a measure of leaf thickness and cellular density, calculated by dividing dry weight of a leaf by its surface area. It is the inverse of Specific Leaf Area. Higher SLW values typically indicate leaves with more layers of mesophyll and higher concentrations of photosynthetic machinery. This parameter is used to characterize leaf-level metabolic investment across different field environments.

156. (A) Its total above-ground biological yield
In the case of forage crops, the entire above-ground part of the plant is typically harvested for animal feed. Therefore, economic yield is essentially equal to total above-ground biological yield produced by the crop. Unlike cereal crops where only grains are harvested, harvest index for forage crops is effectively one hundred percent of the visible biomass, making total dry matter the priority.

157. (D) Weight of 1000 grains
Test weight in cereals is a standard measure of grain quality and size, commonly expressed as the weight of one thousand grains. This parameter reflects efficiency of the grain-filling process and overall health of the crop during

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Transpiration Efficiency is a measure of how effectively a crop converts transpired water into biomass. Mathematically, it is defined as total biological yield produced divided by total amount of water that has passed through the plant via transpiration. This ratio is a key component in yield equations for water-limited environments, indicating carbon gain achieved per unit of water lost to atmosphere.

103. (C) Light is distributed as uniformly as possible over all leaf surfaces
Duncan's model for canopy architecture suggests that yield is maximized when light is distributed uniformly across all leaf surfaces rather than concentrated on the top layer. By using erect leaves at the top and more horizontal leaves at the bottom, a crop can achieve a balanced distribution of solar radiation. This ensures a larger volume of the canopy remains photosynthetically active and productive.

104. (D) Leaf Area Duration
Leaf Area Duration is the best metric to quantify the benefit of the "stay-green" trait. It measures total amount of green leaf area maintained over time. Varieties that remain green longer into the grain-filling period have a higher duration, providing a sustained source of photoassimilates. This leads to better kernel filling and higher final yields, as photosynthetic machinery stays functional during reproduction.

105. (A) $g \cdot m^{-2} \cdot day^{-1}$
Net Assimilation Rate represents the increase in dry weight per unit of leaf area per unit of time. Its standard units are grams per square meter of leaf area per day. This parameter reflects the net photosynthetic efficiency of the plant's leaves after accounting for respiratory losses. It is a fundamental component of crop growth analysis, used to evaluate productivity changes.

106. (A) Thick and structurally dense
Specific Leaf Area is the ratio of leaf area to leaf weight. A low SLA indicates that a leaf is relatively heavy for its size, which usually means it is thick and structurally dense. Such leaves often have multiple layers of palisade cells and high concentrations of photosynthetic components per unit area. This trait is frequently found in sun-adapted or water-stressed crop plants.

107. (D) Similar with a much higher harvest index
Modern semi-dwarf wheat varieties differ from traditional tall varieties primarily in dry matter partitioning rather than total biomass. Under favorable conditions, both types may produce similar total biological yields. However, semi-dwarf varieties have a much higher harvest index because they allocate a significantly greater proportion of biomass to grains instead of stems. This shift was a cornerstone of Green Revolution productivity.

108. (D) Number of productive tillers/branches per unit area
In the analysis of yield structure, the number of productive tillers or branches per unit area is typically the most plastic component. It responds strongly to environmental factors such as planting density, nutrient availability, and water status. While components like individual grain weight are more genetically stable, the crop's ability to adjust tillering allows it to adapt sink capacity to prevailing resources.

109. (C) Sink size
Sink size is a physiological concept that defines the potential capacity of an organ, such as a grain or tuber, to store photoassimilates. It is determined by physical factors such as total volume and number of cells capable of accumulation. Establishing a large sink size during early stages of reproductive development is essential for achieving high yields, setting the limit for filling.

110. (A) I, II and IV
Canopy architecture significantly impacts light interception. Erectophile canopies, with vertical leaves, are optimal for high-density stands because they allow sunlight to penetrate deeper, illuminating more leaf area. In contrast, planophile canopies have horizontal leaves that are efficient at low leaf area indices but cause rapid light attenuation. These classifications help agronomists understand how different plant structures influence total photosynthetic output.

111. (D) Highly horizontal (planophile)
A light extinction coefficient value approaching 1.0 indicates that a crop canopy is highly efficient at intercepting light in its uppermost layers. This is a characteristic of planophile architecture, where leaves are oriented horizontally. In such canopies, sunlight is rapidly attenuated, leaving

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lower leaves in deep shade. While effective for capturing all light at low LAI, it limits productivity in dense stands.

112. (B) 95% of incident PAR is intercepted
Critical Leaf Area Index is a physiological landmark in canopy development defined as the point where ninety-five percent of incident photosynthetically active radiation is intercepted. At this stage, the canopy is effectively capturing almost all available light energy. Increasing leaf area beyond this point provides diminishing returns for photosynthesis and may even lead to decreased growth rates as shading increases respiration.

113. (C) Abscisic Acid (ABA)
Abscisic Acid is the primary phytohormone involved in regulation of stomatal conductance during water stress or high vapor pressure deficit. When plants sense a moisture deficit, ABA accumulates in guard cells, triggering a signaling cascade that leads to stomatal closure. This rapid response is vital for reducing transpiration and preventing desiccation of tissues, although it also restricts entry of CO_2 for photosynthesis.

114. (D) The dark period is shorter than a critical length
Long-day plants initiate their reproductive phase when the duration of the daily dark period falls below a specific critical threshold. Although named "long-day" plants, they actually respond to the length of the night. As nights get shorter in spring and early summer, these plants sense the change via their phytochrome system and trigger floral induction, ensuring reproduction during favorable seasons.

115. (A) At which developmental rate is zero
The base temperature is a fundamental physiological parameter used in thermal time calculations. It represents the lowest temperature at which the metabolic processes driving plant development can occur. Below this baseline, the rate of development is effectively zero. Different crops have different base temperatures depending on their evolutionary origin, and correctly identifying this value is essential for accurately modeling crop phenology.

116. (B) Highly variable cloud cover and sunshine duration
Heliothermal Units are particularly effective for predicting crop maturity in regions with unpredictable weather and frequent cloud cover. Unlike Growing Degree Days, which only consider temperature, HTUs incorporate the actual hours of bright sunshine. This accounts for energy supplied by direct solar radiation, essential for growth. In cloudy environments, HTUs provide a more realistic measure of the cumulative energy the crop utilized.

117. (B) Community/population performance
Donald's ideotype concept introduced a paradigm shift in plant breeding by focusing on performance of the entire plant community rather than individual plants. He argued that traits making an individual plant highly competitive, such as large size and spreading branches, often reduce overall yield of a dense population. Breeding for "weak competitors" optimized for community harvest index allows for higher productivity.

118. (A) Thick, sturdy culms and reduced height
The New Plant Type rice model incorporated structural features specifically designed to improve lodging resistance, which is essential for high-yielding varieties. By breeding for reduced plant height and significantly thicker, sturdier culms, the model ensured plants could support heavy panicles without falling over. This structural integrity allows for application of high nitrogen levels and maintains efficient canopy architecture throughout grain filling.

119. (C) Effective transpirational cooling and open stomata
Canopy Temperature Depression is a measure of the difference between air temperature and the temperature of the crop canopy. A high CTD indicates the canopy is significantly cooler than surrounding air. This cooling effect is driven by active transpiration, which requires open stomata and functional root systems. In hot environments, high CTD is a positive indicator of the plant's metabolic activity.

120. (A) I, III, IV, and V
Using an Infrared Gas Analyzer to measure photosynthesis requires precise monitoring of air flow and the difference in CO_2 mole fraction between reference and sample air. Additionally, humidity must be accounted for to correctly

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calculate gas exchange rates. Modern systems can also use these measurements to estimate the internal CO_2 concentration of the leaf, providing a detailed assessment of physiological status.

121. (B) Beer-Lambert Law
Ceptometers estimate Leaf Area Index by measuring interception of photosynthetically active radiation within the crop canopy. They apply the Beer-Lambert Law, which mathematically relates attenuation of light to the quantity of leaf area present. By comparing light levels above and below the canopy, and making assumptions about leaf orientation, these instruments provide a non-destructive way to quantify canopy structure and potential.

122. (A) Pressure chamber (Scholander bomb)
The pressure chamber, also known as the Scholander bomb, is a standard tool used to measure the water potential of a leaf or stem. It works by placing a severed sample in a sealed chamber with the petiole protruding. External air pressure is gradually increased until xylem sap just appears at the cut surface, providing an accurate measure of plant water stress.

123. (D) Harvest index via semi-dwarf genes
The historical significance of crop physiology in the Green Revolution was its focus on improving Harvest Index. This was achieved primarily through introduction of semi-dwarf genes in wheat and rice. These genes reduced plant height, preventing lodging and allowing for allocation of more photoassimilates to grains rather than stems. This physiological shift dramatically increased the efficiency of converting inputs into edible yield.

124. (D) Kernel abortion and reduced grain set
In maize, the silking stage is a highly sensitive period where physiological stress can have devastating effects on yield. Stress at this time can disrupt pollination and fertilization, leading to significant kernel abortion and reduced grain set. Even if the rest of the season is favorable, failure to establish a high number of kernels during this critical window permanently limits the final productivity.

125. (C) 16 ATP
Biological nitrogen fixation is a metabolically expensive process for pulses and other legumes. The nitrogenase enzyme complex requires approximately sixteen molecules of ATP to reduce a single molecule of atmospheric nitrogen into ammonia. Additionally, the process requires high-energy electrons. This significant energy requirement is provided by the host plant in the form of carbohydrates, explaining why maximum yields are limited.

126. (B) Geocarpy (subterranean fructification)
Groundnut is unique among major oilseeds due to the physiological phenomenon of geocarpy. After flowers are pollinated above ground, a specialized structure called a peg elongates and pushes the developing embryo into the soil. Pods then develop and mature underground. This subterranean fructification protects the developing seeds from aerial predators but also requires specific soil conditions for successful pegging and pod development.

127. (D) Enhancing photosynthetic capacity per unit of transpired water
In Passioura's yield equation, Transpiration Efficiency represents biomass produced per unit of water used. Improving TE involves physiological modifications that allow the plant to fix more carbon while minimizing water loss. This can be achieved by enhancing photosynthetic capacity or by more efficiently regulating stomatal aperture. Selecting for higher TE is a major goal for improving crop performance in water-limited environments.

128. (B) Vertical (erect) leaves at the top, horizontal at the bottom
Duncan's model suggests that ideal canopy architecture for maximizing photosynthesis involves a transition in leaf angle. Vertical or erect leaves are most efficient at the top of the canopy because they allow sunlight to penetrate deeper. Conversely, horizontal leaves are better suited for bottom layers to capture remaining low-intensity light. This arrangement ensures light is distributed more effectively across the canopy.

129. (B) Linear phase of vegetative growth and early reproduction
Crop Growth Rate typically reaches its peak during mid-season, specifically during the linear phase of vegetative expansion and the transition to early reproduction. At this time, the Leaf Area Index is high enough to intercept most incident light, and the proportion of active

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93. (D) Cloud cover via bright sunshine hours
Heliothermal Units enhance the thermal time framework by explicitly incorporating actual duration of bright sunshine received by the crop. By multiplying daily thermal units by sunshine hours, this index accounts for the influence of solar radiation intensity and cloud cover. This is particularly important in regions with variable weather, as it provides a more accurate representation of energy available for development.

94. (A) Reduce intra-plant competition and increase harvest index
The New Plant Type rice model was designed with the hypothesis that eliminating unproductive tillers would reduce internal competition for nutrients and carbohydrates. By focusing plant resources into fewer, higher-quality tillers with large panicles, the model aimed to improve overall harvest index. This architectural change was intended to create a more efficient plant that can support higher grain yields in the tropics.

95. (D) Deep root activity and stomatal conductance under heat/drought
Canopy Temperature Depression is a valuable physiological trait used to select for drought and heat tolerance. It measures how much cooler the crop canopy is compared to surrounding air. A high CTD value indicates the plant is effectively transpiring, which requires open stomata and functional, deep root systems. This trait identifies varieties that can maintain metabolic activity under stressful environmental conditions.

96. (B) Open gas exchange system with precise flow control
An open-system Infrared Gas Analyzer provides the most precise measurements of leaf photosynthesis by continuously passing a fresh stream of air through the leaf chamber. By maintaining a constant flow rate and measuring the difference in CO_2 concentration between air entering and leaving the chamber, the system can calculate steady-state assimilation rates. This setup avoids buildup of humidity and CO_2 depletion.

97. (B) Red and Near-Infrared
The SPAD meter estimates chlorophyll content by measuring transmittance of light at two specific wavelengths: 650 nm (red) and 940 nm (near-infrared). Chlorophyll strongly absorbs red light while transmitting near-infrared light. By comparing the ratio of transmittance at these two wavelengths, the instrument provides a SPAD value that reflects the relative greenness and nitrogen status of the leaf tissue.

98. (B) The resistance to water vapor flux from the leaf
A steady-state porometer is a device used to quantify the resistance or conductance of a leaf to the movement of water vapor through stomata. It works by measuring humidity in a small chamber placed against the leaf surface and maintaining a constant environment. This measurement is crucial for understanding how plants regulate water use and gas exchange in response to the environment.

99. (A) Early seedling to tillering
Relative Growth Rate is typically at its maximum during the earliest stages of a crop's life cycle, such as the period from seedling emergence to tillering in wheat. During this time, almost all plant biomass consists of active photosynthetic tissue, and there is minimal non-productive structural or storage material. As the plant matures and builds more stems, RGR naturally declines.

100. (A) I and II
Pulse crops face several physiological challenges that limit their yield potential. In pigeonpea, flower and pod abscission can be extremely high, sometimes exceeding eighty percent. Furthermore, indeterminate types often experience significant competition for resources between ongoing vegetative growth and the developing reproductive organs. These factors together contribute to the relatively low and unstable harvest indices often observed in many traditional varieties.

101. (D) The siliqua and seeds
During the final phase of the mustard life cycle, the primary metabolic sink is represented by developing siliqua and seeds. At this stage, the plant mobilizes nutrients and photoassimilates from leaves and stems to support rapid accumulation of oil and protein in seeds. The strength of this sink during the ripening process is a major determinant of final seed weight and oil content.

102. (B) $\frac{\text{Biological yield}}{\text{Total water transpired}}$

139. (D) Red to Far-Red light
Phytochrome is a specialized pigment in plants that acts as a light-sensitive switch, mediating photoperiodic and other developmental responses. It exists in two interconvertible forms that respond to the ratio of red to far-red light. By sensing these changes in light quality, particularly at dawn and dusk, the plant can accurately determine length of the night and coordinate its developmental stages.

140. (A) P-1, Q-2, R-3, S-4
Relative Growth Rate is the change in weight per unit of existing weight. Net Assimilation Rate measures weight increase per unit of leaf area. Specific Leaf Area is the ratio of leaf area to leaf weight. Finally, Crop Growth Rate quantifies dry matter accumulation per unit of ground area. These formulas are the fundamental mathematical tools used in standard crop growth analysis.

141. (B) Plant development is driven by the accumulation of daily heat units above a threshold
The concept of Thermal Time assumes the rate of plant development is primarily controlled by temperature. It posits that a plant must accumulate a specific number of heat units, or growing degree days, to transition between developmental stages. These units are only counted when temperature exceeds a certain base threshold, reflecting the biological reality that metabolic processes for development require energy.

142. (B) Compact morphology with erect leaves
A crop ideotype designed for high-density planting should feature a compact morphology and erect leaves. This architecture minimizes physical space each plant occupies and allows sunlight to penetrate deeper into the stand. By reducing mutual shading and intra-plant competition, this design ensures that a greater total leaf area remains photosynthetically active. This is essential for maximizing total biomass and yield.

143. (A) Water Use Efficiency (WUE)
Water Use Efficiency is a physiological index that measures the amount of carbon assimilated per unit of water transpired. At the leaf level, it is often expressed as the ratio of the net photosynthetic rate to the transpiration rate. This parameter reflects the efficiency of the plant in using water to produce biomass. Breeding for higher WUE is a key sustainability strategy.

144. (B) The difference in CO_2 concentration between inlet and outlet air
In an open gas exchange system using an Infrared Gas Analyzer, the net assimilation rate is calculated by measuring the depletion of carbon dioxide as air passes through a leaf chamber. By knowing the precise flow rate of air and the difference in CO_2 concentration between inlet and outlet air, the instrument can determine the amount of carbon fixed per unit time.

145. (A) Measuring light transmittance differences between 650 nm and 940 nm
A SPAD meter assesses leaf greenness by measuring how much light is transmitted through the tissue at two specific wavelengths. Chlorophyll strongly absorbs red light at 650 nm but is transparent to near-infrared light at 940 nm. The instrument calculates the difference in transmittance to provide a relative SPAD value. This value is closely correlated with actual chlorophyll concentration and health.

146. (B) Assimilate partitioning
Assimilate partitioning is the fundamental process that links source capacity with final crop yield. It involves the distribution of photoassimilates produced in source leaves to various sink organs like roots, stems, and seeds. The efficiency and timing of this distribution determine how much total biological yield is ultimately converted into harvested economic yield. Understanding and optimizing this partitioning is a major goal.

147. (B) Developing roots and new leaves
During the early vegetative stages of growth, the plant focuses on building its infrastructure to support future reproduction. The primary sinks for photoassimilates at this time are the developing root system and new leaf primordia. By allocating resources to these organs, the plant maximizes its capacity for nutrient uptake and light interception, ensuring a foundational source capacity to sustain later reproductive development.

148. (B) Excessive overlapping of vegetative and reproductive phases
A major physiological constraint in indeterminate pulse crops is the significant overlap between

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photosynthetic tissue is still large relative to structural biomass. This period represents the most productive window for dry matter.

130. (A) Both A and R are true and R is the correct explanation of A.
Leaf Area Duration is strongly correlated with biomass production because it accounts for both the size of the photosynthetic canopy and length of time it remains functional. By integrating LAI over the entire season, LAD provides a measure of total light-capturing capacity available to the crop. A higher LAD means more cumulative photosynthesis, which directly translates into greater total dry matter accumulation.

131. (B) Leaf area per unit leaf dry weight
Specific Leaf Area is a morphological parameter defined as the ratio of leaf area to leaf dry weight. It indicates how much surface area a plant produces for a given investment in biomass. High SLA values suggest thin leaves with large surface area, often an adaptation to low-light. Conversely, low SLA reflects thicker, denser leaves commonly found in sun-exposed or water-stressed plants.

132. (B) 0.60 - 0.65
The theoretical upper limit for Harvest Index in modern cereal crops is estimated to be around 0.60 to 0.65. This reflects the biological necessity of maintaining a minimum amount of vegetative structure, such as stems and roots, to support developing grain and provide machinery for photosynthesis and nutrient transport. While Green Revolution breeding significantly increased HI, reaching higher values remains challenging.

133. (C) Number of plants/tillers per unit area
The number of plants or productive tillers per unit area is the yield component most directly influenced by management decisions like seeding rate and population density. While individual grain weight and kernels per spike can also vary, initial establishment of the plant stand sets the foundation for the crop's total sink capacity. Agronomists optimize this density to maximize total light interception.

134. (D) Maintaining a steep sucrose concentration gradient from source to sink
Sink strength influences the rate of phloem transport by regulating removal of sugars at the destination. By actively metabolizing or storing sucrose, sinks maintain a low local concentration of these sugars. This creates a steep concentration and pressure gradient between source leaves and sink organs. This gradient is the primary driving force for mass flow through the phloem, ensuring nutrient supply.

135. (A) Higher mutual shading and lower optimum LAI
A "droopy" or horizontal leaf architecture leads to a higher degree of mutual shading within the crop canopy. In such structures, uppermost leaves capture most incoming sunlight, leaving lower layers in deep shade. This reduces the overall efficiency of the canopy and leads to a lower optimum Leaf Area Index, as additional leaf layers quickly become net consumers of energy through respiration.

136. (B) 400 - 700 nm
Photosynthetically Active Radiation refers to the specific range of light wavelengths utilized by green plants to drive the process of photosynthesis. This range, from 400 to 700 nanometers, corresponds closely to the visible light spectrum. Within this window, chlorophyll and other pigments absorb energy to convert carbon dioxide and water into oxygen and high-energy carbohydrates, forming the basis of productivity.

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137. (C) Parasitic respiration by lower leaves decreases overall net growth
When a crop's Leaf Area Index significantly exceeds optimum, lower leaves often receive light intensities below their compensation point. In this shaded state, these leaves consume more carbon through respiration than they can produce through photosynthesis. They effectively become "parasitic" on the rest of the plant. This imbalance increases total respiratory cost and leads to a decrease in overall net growth rate.

138. (A) Thick waxy cuticle
A thick waxy cuticle is a key structural adaptation that helps crop leaves minimize water stress induced by high vapor pressure deficit. This layer serves as a barrier to non-stomatal water loss, reducing evaporation directly from the epidermal surface. By limiting transpiration through the leaf surface, the plant can maintain better internal water status even when the atmosphere is extremely dry.

the final stages of reproduction. A higher test weight indicates well-filled, dense kernels, which is a major component of final harvested yield and grain grade.

158. (A) A non-reducing sugar and chemically stable
Sucrose is the preferred form of carbohydrate for transport in the phloem because it is a non-reducing sugar. This makes it chemically stable and less likely to react with other molecules during long-distance translocation through sieve tubes. Its stability ensures energy-rich sugar can be efficiently moved from source leaves to distant sinks without being prematurely metabolized or degraded during the translocation process.

159. (D) 90 degrees (vertical)
In canopy architecture, a leaf angle of ninety degrees represents a perfectly vertical orientation. This arrangement theoretically minimizes the light extinction coefficient because vertical leaves intercept the least amount of sunlight when the sun is overhead. This allows more radiation to pass through to lower canopy layers. This design is highly efficient for high-density stands, facilitating a more uniform distribution of light.

160. (A) 2, 1, 4, 3
Movement of photoassimilates follows a specific physiological sequence. It begins with synthesis of sucrose in mesophyll cells of source leaves. This sucrose is then actively loaded into phloem sieve tubes. Once in the phloem, it is translocated via mass flow to various sinks throughout the plant. Finally, sucrose is unloaded at sink tissues, where it is used for growth or storage.

161. (A) The LAI where crop growth rate stops increasing
The critical Leaf Area Index is a physiological threshold where the crop canopy intercepts approximately ninety-five percent of incoming solar radiation. At this point, almost all available light is captured, and any further increase in leaf area will not lead to a higher growth rate. Beyond this point, growth often plateaus because marginal gain from new leaves is balanced by respiratory costs.

162. (B) Intercellular CO_2 concentration (Ci)
When high vapor pressure deficit triggers stomatal closure, diffusion of gases into and out of the leaf is significantly restricted. As the plant continues photosynthesis, it consumes carbon dioxide already present within leaf air spaces. Since closed stomata prevent fresh CO_2 from entering, intercellular CO_2 concentration rapidly decreases. This reduction in internal supply directly inhibits the rate of carbon fixation and growth.

163. (D) Vernalization
Vernalization is the process where flowering is induced or accelerated by exposure to a prolonged period of low temperature. This physiological mechanism is common in winter crops, ensuring reproductive development occurs only after winter months have passed. By requiring a "cold treatment," the plant can synchronize its flowering with favorable spring conditions, maximizing its chances for successful pollination and seed development.

164. (A) It is recorded as zero for that day
In calculation of Growing Degree Days, accumulation of heat units is based on temperatures exceeding a specific base threshold. If the mean daily temperature falls below this base temperature, thermal energy is insufficient to drive measurable physiological development. In such cases, the GDD value for that day is recorded as zero, ensuring only temperatures contributing to growth are included in totals.

165. (D) GDD $\times$ Day Length
Photothermal Units are a physiological index used to model development in photoperiod-sensitive crops. They are mathematically calculated by multiplying accumulated daily Growing Degree Days by day length in hours. This integration accounts for the synergistic effect of temperature and light duration on developmental rates. Using PTUs allows researchers to more accurately predict flowering and maturity dates for crops across different latitudes.

166. (A) Competitive features that reduce community yield
Donald's ideotype concept was built on the premise that traits making an individual plant highly competitive often detract from performance of the crop population. He proposed eliminating competitive features, such as spreading branches, to create a plant that thrives in a community. By focusing on "weak competitors" that prioritize partitioning over competition, breeders could achieve higher total yields in modern monocultures.

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167. (B) High membrane thermostability
High membrane thermostability is an important physiological trait used to select for heat tolerance in crops like wheat. It measures the ability of cellular membranes to maintain integrity and function under high-temperature stress. Stable membranes are essential for preventing electrolyte leakage and ensuring metabolic processes like photosynthesis continue. Varieties with high thermostability are better equipped to remain productive during extreme heat.

168. (D) Leaf area enclosed in the chamber
To calculate net photosynthesis rate accurately using an Infrared Gas Analyzer, the instrument must know the exact surface area of leaf enclosed within the measurement chamber. Photosynthesis is typically expressed as amount of carbon fixed per unit leaf area per unit time. Without this structural information, gas exchange data cannot be normalized, making it impossible to compare physiological efficiency correctly.

169. (D) It requires assumptions about canopy leaf angle distribution
A primary limitation of using a Ceptometer to estimate Leaf Area Index is its reliance on mathematical models that require assumptions about the canopy's leaf angle distribution. Since the instrument measures light interception rather than measuring leaves directly, it must use these assumptions to back-calculate LAI. If actual distribution differs from the assumed model, the resulting estimate can be inaccurate.

170. (D) Profuse tillering
Wheat exhibits a high degree of plasticity in its growth habits through the process of tillering. If plant population density is low, individual wheat plants can compensate by producing a greater number of productive tillers. This allows the crop to increase total spikes per unit area, effectively capturing available resources. This physiological flexibility helps stabilize yield even when initial establishment is suboptimal.

171. (B) Maintains active photosynthesis during the grain-filling period
The "stay-green" trait is highly valuable in cereal breeding because it delays senescence of the leaf canopy. By maintaining active chlorophyll and functional photosynthetic machinery for a longer period during grain-filling, the plant can provide a sustained supply of carbohydrates to developing kernels. This leads to higher test weights and increased final yields, especially under environmental conditions that trigger stress.

172. (A) Simultaneous vegetative growth and flowering
Indeterminate varieties of pulses are characterized by their ability to continue vegetative growth even after flowering has commenced. This means new leaves and stems are produced simultaneously with development of flowers and pods. While this growth pattern can provide a larger overall source capacity, it also creates significant internal competition for resources between vegetative and reproductive sinks. This requires careful management.

173. (B) Increased Specific Leaf Area (SLA)
When oilseed crops are subjected to shading or low irradiance, they often exhibit an increase in Specific Leaf Area. This physiological response involves producing larger but thinner leaves to maximize surface area available for light interception with minimal biomass investment. By spreading available resources over a wider area, plants attempt to capture as much limited sunlight as possible to maintain output.

174. (B) The Green Revolution
The Harvest Index concept became a central pillar of plant breeding during the Green Revolution era of the mid-twentieth century. Breeders focused on increasing HI by using dwarfing genes to reduce plant height in wheat and rice. By shifting allocation of dry matter from stems to grains, they were able to dramatically improve efficiency of resource use and productivity.

175. (A) LAI is highly optimal or supra-optimal (dense canopy)
Duncan's canopy simulation indicates that structural arrangement of leaves only significantly impacts total photosynthesis when the canopy is dense. In stands with a very high or supra-optimal Leaf Area Index, mutual shading becomes a major constraint. In these situations, an efficient architecture that allows for better light penetration is essential to prevent a decline in net productivity and biomass.

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176. (B) It integrates the performance of the entire community over ground area
Crop Growth Rate is a population-level measurement that quantifies dry matter accumulated per unit of ground area over time. Unlike measures of individual leaf or plant efficiency, CGR integrates performance of the entire crop community in its actual field environment. It accounts for factors like light interception, mutual shading, and collective metabolic activity, providing a comprehensive view of stand growth.

177. (D) A low overall Crop Growth Rate (CGR)
A crop with a high Net Assimilation Rate indicates individual leaves are efficient at fixing carbon. However, if Leaf Area Index is very low, total photosynthetic surface area available to capture light is insufficient to support rapid biomass accumulation. Since CGR is the product of NAR and LAI, a low LAI will lead to a low overall growth rate.

178. (A) Leaf thickness and density
Specific Leaf Area is mathematically defined as the ratio of leaf area to leaf weight. Consequently, it is inversely proportional to both leaf thickness and leaf density. A low SLA represents a heavy, thick leaf with more layers of mesophyll and higher metabolic investment per unit area. This structural relationship is a key indicator of how plants allocate biomass resources.

179. (B) Artificial reduction in grain number does not alter remaining grain weight
A crop is considered sink-limited if its final yield is restricted by capacity of storage organs rather than supply of photoassimilates. A classic test for this state is to artificially reduce grain number. If remaining grains do not increase in weight despite having more resources available, it indicates they were already at maximum capacity. In such cases, source expansion is ineffective.

180. (A) Both A and R are true and R is the correct explanation of A.
Rice is highly adapted to growing in flooded conditions because it has evolved a specialized physiological mechanism for internal gas transport. Its stems and roots contain extensive aerenchyma tissue, forming a system of interconnected air-filled channels. This allows oxygen from the atmosphere to diffuse down to submerged roots, supporting aerobic respiration in the anaerobic soil environment. This adaptation is essential.

181. (B) Grain weight
In the developmental sequence of wheat, yield components are established at different times. The number of tillers is determined earliest, followed by the number of spikelets and fertility of individual florets. The final component to be established is individual grain weight, which is determined during the grain-filling period between anthesis and maturity. Because it is last, it often reflects late-season stress.

182. (A) Symporters and cell wall invertase
Apoplastic phloem unloading is a complex biochemical process where sugars are moved out of sieve tubes into extracellular space. This process relies on active transport mechanisms, such as sugar symporters, to move solutes against a concentration gradient. Additionally, enzymes like cell wall invertase help break down sucrose, maintaining a steep concentration gradient that ensures continuous flow into sink tissues.

183. (B) Drooping, horizontal leaves
A planophile canopy architecture is characterized by leaves that are predominantly horizontal or drooping. This arrangement is highly effective for intercepting light when the sun is low or when Leaf Area Index is small. However, in dense stands, this structure causes rapid light attenuation and mutual shading, which can limit photosynthetic contribution of lower leaves and reduce overall crop productivity.

184. (D) Light intensity at the top of the canopy
In the Beer-Lambert law, which models light attenuation through a crop stand, I_0 represents the incident solar radiation reaching the top of the canopy. This value serves as the baseline for calculating how much light remains at any given depth within the foliage layers. By understanding intensity at the surface, agronomists can estimate energy available for photosynthesis throughout the vertical profile.

NODIA

185. (B) $e^{\{-2.1\}}$
According to the Beer-Lambert law, the fraction of incident light transmitted through a canopy is given by the formula e to the power of negative k times LAI. With an extinction coefficient of 0.7 and a Leaf Area Index of 3, the exponent

in fully hydrated states.
IV. They exclusively protect against heat stress.
Which of the above statements are correct?
(A) I and III
(B) I, II and III
(C) II and IV
(D) I, III and IV

2003

9. Under prolonged anoxia, which metabolic end-product predominantly accumulates in submerged roots?
(A) Malate
(B) Pyruvate
(C) Citrate
(D) Ethanol

2017

10. Select the correct sequence of events during chilling injury in chilling-sensitive plants.
(A) Membrane phase transition → ROS production → Ion leakage → Necrosis
(B) Ion leakage → Membrane phase transition → Necrosis → ROS production
(C) ROS production → Necrosis → Ion leakage → Membrane phase transition
(D) Necrosis → Ion leakage → ROS production → Membrane phase transition

2017

11. Which modification in membrane lipid composition is essential for maintaining thermotolerance during heat stress?
(A) Increased proportion of linolenic acid
(B) Increased saturation of fatty acids
(C) Decreased lipid saturation
(D) Elimination of all sterols

2021

12. Consider the following statements regarding high light stress:
I. D1 protein degradation occurs in the PSII reaction center.
II. Photoinhibition solely damages PSI.
III. Superoxide is generated primarily via the Mehler reaction.
IV. High light strictly reduces ROS generation.
V. Photo-oxidation bleaches photosynthetic pigments.
Which of the above statements represent an INCORRECT combination?
(A) I, III and V
(B) I, II, IV and V
(C) II and IV
(D) II, III and IV

2025

13. Which specific carotenoid accumulates maximally during peak non-photochemical quenching (NPQ)?
(A) Zeaxanthin
(B) Violaxanthin
(C) Neoxanthin
(D) Lutein

2010

14. Consider the following events in the shade avoidance syndrome (SAS) signaling pathway:
I. Low Red/Far-Red ratio perception
II. Phytochromes shift to Pr form
III. PIF stabilization
IV. Stem elongation
Which of the following represents the correct sequence?
(A) I, II, III, IV
(B) II, I, III, IV
(C) I, III, II, IV
(D) III, II, I, IV

2017

15. The immediate reduction in shoot growth following exposure to saline soil is primarily caused by which mechanism?
(A) The osmotic phase of salt stress
(B) Sodium toxicity in older leaves
(C) Chloride toxicity in meristems
(D) Heavy metal complexation

2003

16. Match the SOS pathway components in List I with their respective functions in List II:
List I: (Components)
P. SOS1
Q. SOS2
R. SOS3
S. NHX1
List II: (Functions)
1. Calcium sensor
2. Plasma membrane Na^+/H^+ antiporter
3. Serine/threonine protein kinase
4. Vacuolar Na^+/H^+ antiporter
(A) P-2, Q-3, R-1, S-4
(B) P-1, Q-2, R-4, S-3
(C) P-4, Q-1, R-2, S-3
(D) P-3, Q-4, R-1, S-2

2004

17. Aluminum toxicity primarily manifests as an immediate inhibition of which physiological process?
(A) Guard cell osmotic adjustment and turgor
(B) Root apical meristem division and activity

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interrupted to provide an accurate measurement of total surface area for growth analysis.

195. (C) Gregory
F.G. Gregory was a pioneering plant physiologist who is primarily credited with mathematical formalization of growth analysis parameters. During the early twentieth century, he developed fundamental concepts and equations for Relative Growth Rate, Net Assimilation Rate, and Leaf Area Ratio. These metrics revolutionized the study of plant growth by providing a systematic way to quantify physiological efficiency and biomass partitioning.

196. (B) Any organ that is a net exporter of photoassimilates
In the study of source-sink dynamics, a source is precisely defined as any organ that produces or mobilizes more photoassimilates than it consumes, making it a net exporter of these nutrients. Most common sources are mature, photosynthetically active leaves. However, during certain developmental stages, other organs like storage roots or stems can also function as sources by mobilizing stored reserves.

197. (D) Flag leaf
As a cereal leaf develops, it undergoes a physiological transition from being a sink to becoming a source. The flag leaf, which is the last leaf to emerge, initially requires photoassimilates from older leaves for its own expansion. Once it matures and its photosynthetic machinery becomes fully functional, it becomes the most important source of carbohydrates for the developing grain and final yield.

198. (A) Adjusting sink load to match limited source capacity
The high rate of flower shedding observed in pigeonpea is a physiological strategy for balancing plant reproductive demand with available resources. Since the plant cannot support development of every flower into a mature pod, it abscises excess to ensure remaining seeds receive adequate nutrients. This mechanism allows the crop to adjust sink load to match current source capacity, which varies with environments.

199. (B) Stem and siliqua wall
In mustard crops, leaves are primary photosynthetic organs during vegetative and early flowering stages. However, as the plant matures and siliqua develop, leaves often senesce. At this point, green walls of the siliqua and the stems take over the role of carbon fixation. This late-stage photosynthesis is vital because it occurs in close proximity to developing seeds, providing a direct source.

200. (B) Reducing excessive early vegetative growth to conserve water for grain filling
Passioura proposed that Harvest Index in dryland crops could be improved by managing timing of water use. By reducing excessive early vegetative vigor, a crop can avoid exhausting soil moisture too quickly. This conservation strategy ensures that a sufficient amount of water remains available during critical flowering and grain-filling stages. This allows the plant to complete its reproductive cycle and produce grain.

201. (B) Spherical or varied leaf angle distribution
A crop canopy with a spherical or varied leaf angle distribution is more efficient at intercepting diffuse or scattered light. Unlike direct sunlight, which comes from a single point, diffuse light comes from all parts of the sky. A varied leaf arrangement ensures some leaves are always oriented favorably to capture scattered radiation. This architectural trait is beneficial in cloudy field environments.

202. (B) Mutual shading causing lower leaves to respire more than they photosynthesize
Characteristic decline in Net Assimilation Rate observed as a crop canopy becomes more dense is fundamentally caused by mutual shading. As Leaf Area Index increases, upper leaves block increasing sunlight from reaching the bottom of the stand. Lower leaves often fall below their light compensation point, meaning carbon loss from respiration exceeds carbon gain from photosynthesis. This imbalance reduces average net efficiency.

203. (B) Time
Leaf Area Duration is a physiological parameter that quantifies total size and persistence of the plant's photosynthetic canopy. Mathematically, it is calculated by integrating the Leaf Area Index over a specified period of time. This metric provides a measure of total opportunity for carbon fixation throughout the season. A higher LAD is strongly correlated with total biomass and final harvested crop yield.

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becomes negative 2.1. This mathematical expression represents how much light penetrates through the leaf area to the ground.

186. (B) High root hydraulic conductivity
To minimize the negative impact of high vapor pressure deficit, a crop must be able to match atmospheric demand for water with rapid supply from the soil. A high root hydraulic conductivity allows the plant to transport water more efficiently to leaves. By maintaining tissue water status, this trait can delay stomatal closure and allow photosynthesis to continue even under stressful conditions.

187. (A) Prevent flowering
Obligate short-day plants require a long, uninterrupted period of darkness to initiate flowering. If this critical dark period is interrupted by even a brief flash of red light, the plant's phytochrome system senses a "long-day" condition. This reset prevents the physiological signals needed for floral induction, effectively keeping the plant in a vegetative state. This sensitivity is a classic photoperiodic characteristic.

188. (A) $\sum(T_{mean} - T_{base})$
Thermal time is calculated as the sum of daily temperatures that contribute to plant development. For each day, the base temperature (below which growth stops) is subtracted from the mean daily temperature. These daily values are then accumulated over a specified period. This summation provides a more accurate way to measure the progress of a crop's life cycle than simple calendar days.

189. (A) Actual solar radiation received for photosynthesis
By incorporating bright sunshine hours into the calculation, Heliothermal Units provide a proxy for the actual amount of solar radiation the crop received. While temperature drives rate of metabolic development, light provides energy for photosynthesis and growth. Accounting for sunshine hours allows the HTU index to capture variations in cloud cover and radiation intensity, offering a comprehensive measure of environmental energy.

190. (A) P-1, Q-2, R-3, S-4
Carbon isotope discrimination is a powerful surrogate for measuring transpiration efficiency. Canopy temperature depression identifies varieties with better root depth and transpirational cooling. Chlorophyll fluorescence is used to assess quantum efficiency of Photosystem II. Finally, Specific Leaf Area provides insights into leaf structural investment. These physiological indices allow plant breeders to screen for complex adaptive traits that contribute to final yield.

191. (A) Intra-plant competition for assimilates
Donald's ideal wheat plant was designed as a uniculm, meaning it produced only a single main stem with no tillers. The primary goal of this architecture was to eliminate intra-plant competition for nutrients and photoassimilates. By focusing all the plant's resources into one large, productive spike, this design aimed to maximize the harvest index and ensure that every individual stem contributes efficiently.

192. (B) Underlying traits and mechanisms that drive yield
Physiological breeding represents a shift away from empirical selection, where breeders focus solely on final grain yield. Instead, it involves targeting specific underlying traits and physiological mechanisms, such as water use efficiency, light interception, or partitioning, that collectively drive yield. By selecting for these components, breeders can more systematically improve crop performance and stability across environments characterized by drought or stress.

193. (A) High sensitivity to rapid fluctuations in ambient humidity and wind
A major challenge when using porometers in the field is high sensitivity to the surrounding environment. Rapid changes in ambient humidity, wind speed, or light can cause the plant to adjust stomatal aperture almost instantaneously, leading to variable readings. To obtain accurate and reproducible data, researchers must take measurements under stable conditions and often need to sample a large number of leaves.

194. (D) Measurement of intercepted light as leaves pass over a scanner
Optical leaf area meters function by measuring the amount of light that is blocked or intercepted by a leaf as it passes through a scanning system. A conveyor belt usually moves the leaf between an array of light-emitting diodes and sensors. The instrument integrates the area where light is

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Tropical or warm-season crops generally have much higher base temperatures than temperate crops. For example, maize, which originated in the tropics, typically has a base temperature around ten degrees Celsius. In contrast, temperate cereals like wheat, barley, and oats have much lower base temperatures, allowing growth in cooler climates.

214. (C) 10 °C
The base temperature for rice is generally accepted to be ten degrees Celsius. This value represents the physiological threshold below which metabolic processes driving rice development effectively cease. Correctly identifying this temperature is essential for calculating thermal time or growing degree days, which are used to predict duration of various growth stages and maturity in different environments and dates.

215. (A) Designing a theoretical plant model optimized for a specific environment
The ideotype concept revolutionized plant breeding by introducing a proactive and systematic approach to variety development. Instead of simply eliminating defects from existing varieties, breeders began to design theoretical plant models with specific morphological and physiological traits optimized for a particular environment. This "design-driven" approach allows breeders to target specific components of yield and efficiency, leading to significant and predictable productivity gains.

216. (B) Low tillering capacity (3-4 heavy panicles)
A fundamental feature of the IRRI New Plant Type for tropical rice was a significant reduction in tillering capacity. Unlike traditional varieties that produce many unproductive tillers, the NPT was designed to produce only three or four sturdy, highly productive tillers with very large, heavy panicles. This architectural shift aimed to minimize intra-plant competition and maximize proportion of biomass partitioned into grain.

217. (B) Transpiration efficiency
Carbon Isotope Discrimination is a valuable physiological tool used as a surrogate measure for transpiration efficiency in C3 plants. During photosynthesis, enzyme RuBisCO discriminates against heavier carbon-13 isotope. Degree of discrimination is related to ratio of intercellular to atmospheric CO_2, controlled by balance of stomatal conductance and photosynthetic rate. Measuring $\Delta^{13}C$ in tissue provides a long-term, integrated measure of plant efficiency.

218. (A) Continuously flowing a known stream of air through the leaf chamber
An open-system Infrared Gas Analyzer is designed to maintain a steady-state environment for the leaf during measurement. It achieves this by continuously flowing a fresh, known stream of air through the leaf chamber. This constant flow prevents buildup of humidity and depletion of carbon dioxide occurring in a closed system. By measuring difference in gas concentrations between inlet and outlet air, system provides accurate.

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219. (C) Nitrogen
The SPAD meter is widely used in precision agriculture to manage nitrogen applications. Because chlorophyll content is closely related to nitrogen status, the SPAD value provides a rapid, non-destructive estimate of how much nitrogen is available. Farmers use this information to determine when to apply supplemental nitrogen fertilizer, ensuring the crop has enough nutrients while minimizing waste and environmental impact.

220. (B) Porometer
A porometer is an essential instrument for rapidly quantifying stomatal resistance or conductance in the field. It measures the rate at which water vapor diffuses from the leaf surface into a small chamber. This data provides immediate insights into how the plant is regulating gas exchange in response to environmental factors like light, humidity, and soil moisture during the growing season.

221. (A) Cloudy weather and foliar diseases
Source limitation during the grain-filling period of wheat occurs when supply of photoassimilates is insufficient to meet demand of developing kernels. This state is often exacerbated by cloudy weather, which reduces incident solar radiation available for photosynthesis. Foliar diseases can also significantly reduce functional green leaf area, further limiting source capacity. When sources are limited, grains may not fully fill.

222. (B) Extended vegetative growth competes directly with pod filling for assimilates
Modern high-yielding indeterminate pulses often exhibit a physiological trade-off where ongoing

vegetative growth competes for resources with developing pods. Because the plant continues to produce new leaves and stem nodes during reproductive phase, photoassimilates are diverted away from seeds to support new growth. This internal competition can restrict rate of pod filling and lead to a lower final harvest index.

223. (B) Transpiration Efficiency
In Passioura's yield framework, Transpiration Efficiency is often considered the most difficult component to improve through breeding. While total water use can be managed through irrigation, and Harvest Index has been increased via genes, TE is closely linked to fundamental biochemical processes of photosynthesis and stomatal regulation. Improvements in TE require subtle adjustments in leaf-level efficiency, making it a challenging target.

224. (C) Net Assimilation Rate
Mathematically, dividing Crop Growth Rate by Leaf Area Index yields Net Assimilation Rate. CGR measures dry matter produced per unit ground area, while LAI represents total leaf area per unit ground area. This calculation provides the average rate of dry matter increase per unit of leaf area. It effectively isolates physiological efficiency of photosynthetic machinery from the influence of canopy size.

225. (A) They become net consumers of assimilates (parasitic)
When the Leaf Area Index of a canopy exceeds the critical threshold, light intensity reaching the lowest leaves often falls below their compensation point. In this deeply shaded environment, the amount of carbon fixed through photosynthesis is less than the amount lost through respiration. As a result, these leaves become "parasitic," consuming photoassimilates produced by upper leaves and reducing net growth.

226. (B) Increased layers of palisade mesophyll and dense cellular packing
Leaves with high Specific Leaf Weight are characterized by structural rigidity and thickness. This is typically due to presence of additional layers of palisade mesophyll cells and more dense packing of cells within tissue. This anatomical arrangement provides mechanical strength and increases concentration of photosynthetic components per unit area. This adaptation allows high-SLW leaves to achieve greater maximum photosynthetic rates.

227. (A) Sink dominance
Sink dominance is a physiological phenomenon in which a strong metabolic sink, such as a rapidly developing grain, effectively dictates the direction and rate of phloem transport. By maintaining a low local concentration of sugars through metabolism, the sink creates a steep pressure gradient that draws photoassimilates from source leaves. This dominance ensures resources are prioritized for the most critical organs.

228. (B) Ambient air temperature
Ambient air temperature is the absolute primary driver for calculating Growing Degree Days. The GDD concept is based on the biological principle that plant developmental rates are directly controlled by accumulation of heat. By using daily maximum and minimum air temperatures to determine the mean, and comparing this to a base threshold, researchers can create a cumulative thermal index.

229. (B) They prioritize community harvest index over individual plant size
Donald's ideotype concept emphasizes "weak competitors" as ideal crop plants because they are designed to perform well in a dense population. Highly competitive plants often produce large structures that shade neighbors and waste resources. In contrast, "weak competitors" have a compact architecture that minimizes intra-plant competition. By prioritizing community harvest index over individual size, these types allow for higher total yields.

230. (B) Light compensation point
The light compensation point is a physiological threshold where photosynthetic carbon dioxide uptake exactly balances respiratory release. At this specific light intensity, net gas exchange is zero. Below this point, leaves consume more energy than they produce, becoming parasitic. Understanding this concept is essential for analyzing canopy productivity, light distribution, and the efficiency of the entire crop community in field environments.

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CHAPTER 04

Abiotic Stress Responses in Plants

2014

1. Which term describes the completely reversible physical deformation of plant tissue upon temporary exposure to mild abiotic stress?
(A) Plastic strain
(B) Elastic strain
(C) Permanent wilting
(D) Cellular senescence

2003

2. Consider the following statements regarding cellular water potential components:
I. Solute potential is universally negative in living plant cells.
II. Pressure potential is always negative in fully turgid cells.
III. Matric potential is highly positive in dry seeds.
Which of the above statements is/are correct?
(A) I and II
(B) III only
(C) I only
(D) II and III

2003

3. Which micrometeorological factor most directly increases the boundary layer resistance over a plant canopy?
(A) High wind speed
(B) Low canopy density
(C) Elevated soil moisture
(D) Dense trichome presence

2021

4. Match the guard cell mechanics features in List I with their respective triggers in List II:
List I: (Features)
P. Stomatal closure
Q. Stomatal opening
R. Ion efflux
S. Malate synthesis
List II: (Triggers)
1. Blue light
2. High VPD
3. ABA accumulation
4. Proton pump activation
(A) P-2, Q-1, R-3, S-4
(B) P-1, Q-2, R-4, S-3
(C) P-3, Q-4, R-1, S-2
(D) P-4, Q-3, R-2, S-1

2004

5. In Passioura's yield model, which physiological modification would directly increase transpiration efficiency under drought?
(A) Increased leaf area index
(B) Enhanced mesophyll conductance
(C) Reduced epicuticular wax
(D) Shallow root architecture

2013

6. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): Ephemeral desert plants typically exhibit dehydration tolerance.
Reason (R): They rapidly complete their life cycle before severe soil water deficit occurs.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2016

7. Which statement correctly identifies the primary cellular function of accumulated proline during osmotic stress?
(A) It acts as a compatible solute for osmotic adjustment.
(B) It permanently replaces structural membrane lipids.
(C) It rapidly degrades structural proteins to release energy.
(D) It functions as the primary electron acceptor in PSI.

2003

8. Consider the following statements regarding LEA proteins:
I. They are highly hydrophilic.
II. They denature rapidly upon boiling.
III. They lack strict three-dimensional structure

NODIA

204. (B) Higher photosynthetic rates per unit leaf area
Specific Leaf Weight is a measure of leaf thickness and structural density. In many crop species, higher SLW values are positively correlated with greater photosynthetic rates per unit of leaf area. This is because thicker leaves typically contain more layers of palisade cells and higher concentrations of chlorophyll and RuBisCO. This increased metabolic investment allows square centimeters of leaf to fix more carbon.

205. (A) Above-ground dry matter only
Standard calculation for the Harvest Index in agronomy assumes biological yield consists of total above-ground dry matter at maturity. While roots are biologically part of total yield, they are almost always excluded from HI calculations in field trials due to extreme difficulty of harvesting and weighing them accurately. This standardized approach allows for consistent comparison of partitioning efficiency across different crop varieties.

206. (B) Increasing grains per spike and individual grain weight
Wheat has a remarkable ability to compensate for low plant populations through flexible yield components. If there are fewer spikes per square meter, the plant can direct more available resources into remaining spikes. This often results in an increase in number of grains per spike and a higher individual grain weight. This plastic response helps the crop maintain its total yield potential.

207. (B) Cytokinin
Cytokinins play a vital role in establishing and maintaining sink strength in developing seeds and fruits. They are primarily known for promoting cell division during early stages of reproductive growth, which determines total number of cells available for storage. Additionally, cytokinins influence activity of enzymes involved in nutrient unloading. By ensuring a large number of active cells, these hormones set capacity.

208. (B) Allows PAR to illuminate a greater total leaf area volume
An erectophile canopy, characterized by vertical leaves, is highly advantageous for high-yielding crop varieties grown at high densities. This architecture allows photosynthetically active radiation to penetrate deeper into the canopy stand, reaching middle and lower leaf layers. By distributing light more evenly across a larger total leaf area volume, this design prevents bottom leaves from becoming parasitic and maximizes overall growth.

209. (A) Lower numerical LAI value
Light extinction coefficient determines how rapidly solar radiation is attenuated as it passes through the canopy. If a crop has a high extinction coefficient, it means leaves are very efficient at intercepting light in upper layers, often due to a horizontal orientation. Consequently, the canopy will reach its critical Leaf Area Index at a lower numerical LAI value compared to erect.

210. (A) Optimum LAI maximizes Crop Growth Rate
Optimum Leaf Area Index and Critical Leaf Area Index are two distinct concepts in crop growth analysis. Optimum LAI is the specific leaf area index at which net crop growth rate is at its maximum, representing the best balance between canopy photosynthesis and total respiration. In contrast, Critical LAI is defined solely by light interception, occurring when 95% of light is captured.

211. (B) Stomatal conductance decreases to restrict further water loss
In response to high atmospheric vapor pressure deficit, plants must balance need for carbon dioxide with risk of excessive dehydration. As VPD increases, rate of transpiration rises, but only up to a point. Once a threshold is reached, the plant typically responds by decreasing its stomatal conductance. This closure restricts further water loss and helps maintain internal water status of leaf tissue.

212. (A) They require specific day lengths to initiate flowering
Photoperiodic sensitivity is a major factor limiting geographical adaptation of many crop varieties, including traditional rice. These plants require specific duration of day or night to trigger transition to flowering. If a variety is moved to a different latitude where seasonal day lengths do not match requirements, it may flower too early or too late, leading to poor synchronization and reduced yield.

213. (C) Maize
Base temperature for growth varies significantly among crop species based on evolutionary origin.

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(C) Leaf stomatal conductance and gas exchange
(D) Chloroplast electron transport efficiency

2003

18. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): Phytochelatins are enzymatically synthesized peptides involved in heavy metal detoxification.
Reason (R): Phytochelatins form direct complexes with heavy metals and sequester them into the central vacuole.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2022

19. Upon binding ABA, PYR/PYL receptors immediately inhibit which specific negative regulators?
(A) SnRK2 kinases
(B) Calmodulin-like proteins
(C) Heat shock transcription factors
(D) Type 2C protein phosphatases (PP2Cs)

2011

20. Consider the following statements regarding cytokinin dynamics under abiotic stress:
I. Cytokinins generally promote stress-induced senescence.
II. Cytokinin levels usually drop during drought stress.
III. Cytokinins act as positive regulators of extreme cold tolerance.
Which of the above statements represent an INCORRECT combination?
(A) I and II
(B) I and III
(C) II only
(D) II and III

2005

21. Which cellular compartment is the primary site of singlet oxygen generation during high light stress?
(A) Mitochondria
(B) Chloroplasts
(C) Peroxisomes
(D) Cytosol

2006

22. Match the enzymatic antioxidants in List I with their primary substrates in List II:
List I: (Antioxidants)
P. Superoxide Dismutase
Q. Catalase
R. Ascorbate Peroxidase
S. Glutathione S-Transferase
List II: (Substrates)
1. Hydrogen peroxide
2. Superoxide anion
3. Lipid hydroperoxides
4. Ascorbate and Hydrogen peroxide
(A) P-2, Q-1, R-4, S-3
(B) P-1, Q-2, R-3, S-4
(C) P-3, Q-4, R-1, S-2
(D) P-4, Q-3, R-2, S-1

2010

23. What is the terminal electron donor for the regeneration of ascorbate in the Foyer-Halliwell-Asada cycle?
(A) NADPH
(B) NADH
(C) FADH2
(D) Plastoquinone

2008

24. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): Severe abiotic stress strictly induces plastic deformation in plant cell walls.
Reason (R): Plastic deformation represents irreversible tissue damage or structural alteration.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2021

25. Which component of cellular water potential is primarily responsible for maintaining cell turgor?
(A) Solute potential
(B) Matric potential
(C) Gravitational potential
(D) Pressure potential

2022

26. Consider the following statements concerning energy balance in plant canopies:
I. Transpiration acts as a major cooling mechanism.
II. High humidity increases the latent heat of

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(A) Ethylene
(B) Cytokinin
(C) Abscisic acid
(D) Salicylic acid

2024

44. Consider the following statements regarding specific ROS:
I. Hydrogen peroxide is uncharged and can cross cell membranes.
II. The hydroxyl radical is the least reactive ROS.
III. Superoxide is a strong electrophile that rapidly degrades DNA.
IV. Singlet oxygen is formed purely by enzymatic reduction.
Which of the above statements represent an INCORRECT combination?
(A) II, III and IV
(B) I and II
(C) I, III and IV
(D) II and IV

2011

45. Which enzymatic antioxidant uniquely converts hydrogen peroxide directly to water and oxygen without requiring a specific cellular reductant?
(A) Catalase
(B) Ascorbate peroxidase
(C) Glutathione reductase
(D) Superoxide dismutase

2009

46. During non-enzymatic ROS scavenging, lipid-soluble antioxidants are crucial for protecting which specific cellular structure?
(A) Plasma membrane
(B) Nucleolus
(C) Cell wall
(D) Cytosol

2008

47. Consider the following statements defining abiotic stress concepts:
I. Eustress always leads to rapid cell death.
II. Elastic deformation signifies permanent crop yield loss.
III. Strain is the biological response to an environmental stressor.
IV. Plastic deformation occurs when the elastic limit is exceeded.
V. Stress strictly refers to optimal environmental conditions.
Which of the above statements represent an INCORRECT combination?
(A) II, III and IV
(B) I, III and V
(C) I, II and V
(D) III, IV and V

2025

48. Which term specifically defines the total chemical potential of water in a plant cell compared to pure water?
(A) Solute potential
(B) Pressure potential
(C) Osmotic pressure
(D) Water potential

2008

49. In the context of energy balance, what is the most significant mechanism plants use to dissipate excess sensible heat?
(A) Respiration
(B) Photosynthesis
(C) Guttation
(D) Transpiration

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2006

50. Which of the following is a correct statement regarding guard cell responses to elevated Vapor Pressure Deficit (VPD)?
(A) Guard cells increase potassium influx.
(B) Guard cells lose turgor, leading to stomatal closure.
(C) Stomatal pores widen to cool the leaf.
(D) Stomata open fully irrespective of ABA levels.

2010

51. Which statement INCORRECTLY describes Passioura's yield model components?
(A) It relies on total water transpired by the crop.
(B) Harvest index is irrelevant to final yield.
(C) Water use efficiency directly influences yield.
(D) It is fundamentally expressed as Yield = Transpiration × WUE × Harvest Index.

2013

52. Which of the following is a correct pair regarding drought adaptation strategies?
(A) Dehydration tolerance – LEA accumulation
(B) Drought escape – Deep root system depth
(C) Dehydration avoidance – Osmotic adjustment
(D) Drought escape – Leaf rolling and curling

2009

53. Which of the following is an INCORRECT pair of an osmoprotectant and its typical biochemical nature?

nitrogen.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2010

35. The rapid turnover of the D1 protein is a specialized repair mechanism directly mitigating which type of stress?
(A) Low light stress
(B) Heavy metal toxicity
(C) Osmotic stress
(D) Photoinhibition of PSII

2012

36. Consider the following statements regarding photoprotection mechanisms:
I. The xanthophyll cycle converts zeaxanthin to violaxanthin under high light.
II. NPQ safely dissipates excess excitation energy as heat.
III. Alternative electron sinks prevent over-reduction of the photosynthetic electron transport chain.
Which of the above statements is/are correct?
(A) I and III
(B) II and III
(C) I only
(D) I, II and III

2005

37. Which photoreceptor is primarily responsible for perceiving the Red/Far-Red ratio changes in a canopy?
(A) Phototropin
(B) Phytochrome
(C) Cryptochrome
(D) UVR8

2001

38. Match the stages/aspects of salinity stress in List I with their primary characteristics in List II:
List I: (Stages/Aspects)
P. Osmotic phase
Q. Ionic phase
R. Exclusion
S. Compartmentalization
List II: (Characteristics)
1. Slow onset, specific tissue damage
2. Rapid growth reduction, water deficit
3. Sequestration into central vacuole
4. Blocking Na^+ entry at roots
(A) P-2, Q-1, R-4, S-3
(B) P-1, Q-2, R-3, S-4
(C) P-4, Q-3, R-2, S-1
(D) P-3, Q-4, R-1, S-2

2016

39. The Salt Overly Sensitive (SOS) pathway fundamentally relies on the intracellular sensing of which secondary messenger?
(A) Calcium ions
(B) ABA
(C) Reactive oxygen species
(D) Inositol triphosphate

2018

40. Consider the following events in heavy metal detoxification via phytochelatins:
I. Phytochelatin synthase activation
II. Metal entry into the cytosol
III. Sequestration of complex into vacuole
IV. Complexation of metal by phytochelatin
Which of the following represents the correct sequence?
(A) II, I, IV, III
(B) I, II, III, IV
(C) II, IV, I, III
(D) IV, II, I, III

2019

41. Cadmium primarily disrupts cellular metabolism by replacing which essential cofactor in vital metalloenzymes?
(A) Magnesium
(B) Potassium
(C) Manganese
(D) Zinc

2008

42. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): SnRK2 kinases act as central positive regulators in the ABA signaling pathway.
Reason (R): Under stress conditions, SnRK2s are actively dephosphorylated by PP2Cs to induce stomatal closure.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2017

43. Which phytohormone fundamentally antagonizes the senescence-promoting effects of stress?

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vaporization transfer.
III. Net radiation equals the sum of sensible heat, latent heat, and soil heat fluxes.
IV. Stomatal closure rapidly decreases sensible heat loss.
Which of the above statements are correct?
(A) I and III
(B) I, II and IV
(C) II and III
(D) I, III and IV

2001

27. How does a sudden increase in Vapor Pressure Deficit (VPD) affect stomatal conductance in most mesophytic crops?
(A) Stomatal opening to increase evaporative cooling
(B) Stomatal closure to prevent excessive water loss
(C) Guard cell malate synthesis and ion regulation
(D) Guard cell ABA receptor signaling and response

2019

28. Match the strategies for improving Water Use Efficiency (WUE) in List I with their physiological mechanisms in List II:
List I: (Strategies)
P. Deep rooting
Q. Early maturity
R. Epicuticular wax
S. Narrow leaves
List II: (Mechanisms)
1. Minimizes boundary layer resistance
2. Accesses lower soil moisture reserves
3. Reduces cuticular transpiration
4. Evades terminal drought
(A) P-2, Q-4, R-3, S-1
(B) P-1, Q-2, R-4, S-3
(C) P-4, Q-3, R-1, S-2
(D) P-3, Q-1, R-2, S-4

2025

29. Dehydration avoidance is best characterized by which specific plant adaptation?
(A) Maintaining high tissue water potential during drought
(B) Surviving severe cellular desiccation and drying
(C) Rapid abscission of all vegetative leaf tissues
(D) Cessation of root growth and water acquisition

2015

30. Consider the following statements regarding osmoprotectants:
I. Glycine betaine is synthesized in chloroplasts.
II. Trehalose acts solely as an energy source.
III. They perturb enzyme structures at high concentrations.
IV. Proline biosynthesis uses glutamate as a precursor.
V. They maintain hydration shells around proteins.
Which of the above statements are correct?
(A) I, IV and V
(B) II, III, IV and V
(C) I and IV
(D) I, II and III

2012

31. The structural transition of intrinsically disordered LEA proteins into alpha-helices is primarily triggered by which environmental factor?
(A) Cellular desiccation
(B) Prolonged hypoxia
(C) High light levels
(D) Low temperature

2003

32. Select the correct sequence of anatomical and metabolic responses to waterlogging.
(A) Hypoxia → Ethylene accumulation → Cell death/lysis → Aerenchyma formation
(B) Ethylene accumulation → Aerenchyma formation → Cell death/lysis → Hypoxia
(C) Aerenchyma formation → Cell death/lysis → Hypoxia → Ethylene accumulation
(D) Cell death/lysis → Hypoxia → Ethylene accumulation → Aerenchyma formation

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2025

33. Which cellular event is the most common direct cause of freezing injury in non-acclimated plants?
(A) Accumulation of compatible solutes
(B) Rapid intracellular ice crystal formation
(C) Enhanced fluidity of the plasma membrane
(D) Excessive vacuolar expansion

2005

34. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): Heat Shock Proteins (HSPs) function primarily as molecular chaperones during high-temperature stress.
Reason (R): HSPs actively degrade denatured proteins into individual amino acids to recycle

(A) Proline – Amino acid
(B) Mannitol – Lipid
(C) Glycine betaine – Quaternary ammonium compound
(D) Trehalose – Disaccharide

2012

54. All of the following are characteristics of Dehydrins EXCEPT:
(A) They are a sub-family of LEA proteins.
(B) They possess intense enzymatic hydrolytic activity.
(C) They lack a defined structure in aqueous solution.
(D) They exhibit a highly conserved K-segment.

2008

55. What is the most appropriate description of aerenchyma tissue function during waterlogging?
(A) Facilitating oxygen transport to submerged roots
(B) Storing toxic heavy metals within root vacuoles
(C) Restricting gas diffusion across root barriers
(D) Actively synthesizing ethylene in cortical cells

2004

56. Cold-induced membrane rigidification directly leads to which physiological consequence?
(A) Hyper-fluidity of the lipid bilayer
(B) Increased activity of membrane-bound H^+-ATPases
(C) Leakage of cellular electrolytes
(D) Enhanced root water uptake

2014

57. The primary effect of heat stress on cellular membranes is:
(A) Irreversible stiffening
(B) Enhanced aquaporin closure
(C) Increased sterol rigidification
(D) Membrane hyper-fluidity

2015

58. Based on its structure, which protein complex is most vulnerable to photo-oxidative damage under high light?
(A) Cytochrome b6f
(B) ATP synthase
(C) PSII reaction center
(D) PSI core complex

2001

59. The conversion of violaxanthin to zeaxanthin provides an advantage under high light by:
(A) Increasing quantum yield
(B) Dissipating excess energy as heat
(C) Enhancing CO_2 fixation
(D) Directly synthesizing ATP

2006

60. The primary trigger for the Shade Avoidance Syndrome (SAS) is:
(A) Extremely high total irradiance
(B) Depletion of soil nitrogen
(C) High UV-B radiation
(D) A low Red to Far-Red ratio

2006

61. Based on physiological responses, what inference can be drawn about the initial growth inhibition during salinity stress?
(A) It mirrors the response to pure water deficit.
(B) It is solely due to sodium toxicity.
(C) It is caused by extreme chloride accumulation in leaves.
(D) It reflects enhanced nutrient uptake.

2007

62. Which mechanism allows halophytes to survive high cytosolic sodium levels?
(A) Exclusion of sodium from the root cortex
(B) Complete substitution of potassium with sodium
(C) Rapid vacuolar compartmentalization of sodium
(D) Enhanced apoplastic phloem loading

2016

63. A major disadvantage of aluminum toxicity in acidic soils is:
(A) Lateral root and apex inhibition
(B) Uncontrolled shoot elongation
(C) Premature and rapid flowering
(D) Enhanced soil nutrient uptake

2013

64. Which term specifically defines metal-binding, cysteine-rich peptides synthesized enzymatically in response to heavy metals?
(A) Metallothioneins
(B) Dehydrins
(C) Chaperonins
(D) Phytochelatins

2010

65. Which of the following is the primary cellular receptor complex for Abscisic Acid (ABA) signaling?
(A) TIR1
(B) PYR/PYL/RCAR

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(D) Singlet oxygen

2003

91. The simultaneous activity of SOD and CAT prevents the cellular accumulation of:
(A) Water
(B) Hydroxyl radicals via the Haber-Weiss reaction
(C) Carbon dioxide
(D) ATP

2014

92. The major disadvantage of the non-enzymatic ROS scavenging system compared to the enzymatic system is:
(A) It requires continuous stoichiometric regeneration of reductants.
(B) It strictly operates in the dark.
(C) It can only scavenge singlet oxygen.
(D) It produces highly toxic byproducts.

2017

93. Which term specifically defines the point at which plant tissue deformation under stress becomes permanent?
(A) Yield threshold
(B) Turgor point
(C) Elastic limit
(D) Plasticity index

2024

94. What is the primary equation governing water potential in mature, vacuolated plant cells?
(A) Psi = Solute Potential + Pressure Potential
(B) Psi = Matric Potential − Pressure Potential
(C) Psi = Solute Potential − Matric Potential
(D) Psi = Pressure Potential − Gravitational Potential

2008

95. Identify the correct statement regarding canopy energy balance.
(A) Smaller leaves have thinner boundary layers and higher sensible heat loss.
(B) The boundary layer resistance is independent of leaf size.
(C) Wind strictly decreases transpiration rates.
(D) Net radiation is solely composed of long-wave radiation.

2001

96. Identify the INCORRECT statement about guard cell mechanics.
(A) Stomatal opening requires ATP-driven proton efflux.
(B) Malate acts as a primary counter-ion for potassium.
(C) Elevated cytosolic calcium triggers stomatal closure.
(D) ABA promotes the opening of inward-rectifying potassium channels.

2013

97. Which of the following is a correct pair regarding yield models?
(A) Passioura's Model – Yield = Water Transpired × WUE × Harvest Index
(B) Harvest Index – Ratio of root to shoot biomass
(C) Water Use Efficiency – Total carbon fixed minus respiration
(D) Transpiration Efficiency – Water applied per unit area

2021

98. Which of the following is an INCORRECT pair regarding drought adaptation strategies?
(A) Resurrection plants – Dehydration tolerance
(B) Phreatophytes – Drought escape
(C) Desert ephemerals – Drought escape
(D) Succulents – Dehydration avoidance

2016

99. All of the following are recognized compatible solutes EXCEPT:
(A) Proline
(B) Pinitol
(C) Trehalose
(D) Hydrogen peroxide

NODIA

2019

100. What is the most appropriate definition of the term "Late Embryogenesis Abundant"?
(A) Proteins accumulating during seed desiccation
(B) Proteins strictly degraded during embryogenesis
(C) Enzymes responsible for embryo abortion events
(D) Structural proteins of the protective seed coat

2013

101. The transition from aerobic respiration to fermentation during anoxia restricts cellular ATP yield per glucose molecule to:
(A) 0 ATP
(B) 2 ATP
(C) 12 ATP
(D) 36 ATP

2006

78. By eliminating the necessity for oxygen, fermentative metabolism in waterlogged roots ensures the continued production of:
(A) Large amounts of ATP
(B) Minimal ATP required for brief survival
(C) Structural lipids
(D) Chlorophyll

2025

79. A significant advantage of accumulating unsaturated fatty acids during cold acclimation is:
(A) Prevention of membrane transition to a gel phase
(B) Decreased membrane permeability
(C) Complete elimination of ion transport
(D) Rapid initiation of cellular freezing

2011

80. Which term defines the acquired ability of a plant to survive lethal high temperatures following exposure to a mild heat pretreatment?
(A) Freezing tolerance
(B) Chilling requirement
(C) Photoprotection
(D) Thermotolerance

2024

81. What is the primary biological consequence of extensive photo-oxidation in chloroplasts?
(A) Pigment bleaching and lipid peroxidation
(B) Enhanced sugar synthesis
(C) Increased D1 protein synthesis
(D) Accumulation of compatible solutes

2015

82. Identify the correct statement regarding alternative electron sinks during high light stress.
(A) Mehler reaction dissipating electrons safely
(B) Carbon fixation being the only electron sink
(C) Alternative sinks completely replacing NPQ
(D) Photorespiration acting to protect PSII

2013

83. Identify the INCORRECT statement concerning shade avoidance.
(A) It results in increased stem elongation.
(B) It causes an upward bending of leaves (hyponasty).
(C) It diverts resources away from leaf expansion.
(D) It is triggered by a high Red to Far-Red ratio.

2022

84. Which of the following is a correct pair?
(A) Ionic phase – Occurs within minutes
(B) Salt tolerance – Complete absence of vacuoles
(C) Osmotic phase – Driven strictly by Na^+ toxicity
(D) Osmotic phase – Immediate growth arrest

2001

85. Which of the following is an INCORRECT pair?
(A) NHX1 – Plasma membrane
(B) SOS1 – Plasma membrane
(C) SOS2 – Kinase
(D) SOS3 – Calcium binding

2009

86. All of the following are consequences of Aluminum toxicity EXCEPT:
(A) Callose deposition in roots
(B) Root apex swelling
(C) Disruption of the root cytoskeleton
(D) Enhanced root hair proliferation

2025

87. What is the most appropriate role of metallothioneins?
(A) To strictly sequester toxic metals into the cell wall
(B) To act as transcription factors during drought
(C) To degrade accumulated heavy metals
(D) To chelate metals via cysteine-rich domains

2014

88. ABA-induced stomatal closure heavily depends on the activation of which ion channels?
(A) Plasma membrane anion channels (e.g., SLAC1)
(B) Vacuolar malate channels
(C) Potassium inward-rectifying channels
(D) Calcium efflux channels

2024

89. Cytokinin application to drought-stressed leaves generally results in:
(A) Immediate stomatal closure
(B) Rapid chlorophyll degradation
(C) Increased root elongation
(D) Delayed onset of senescence

2012

90. Based on their biochemical properties, which ROS is considered the most highly reactive and destructive, lacking any specific enzymatic scavenger?
(A) Hydroxyl radical
(B) Hydrogen peroxide
(C) Superoxide

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2006

114. Superoxide Dismutase (SOD) mitigates oxidative damage by catalyzing the dismutation of superoxide into:
(A) Oxygen and Water
(B) Hydrogen peroxide and Oxygen
(C) Hydroxyl radical and Water
(D) Singlet oxygen and Water

2018

115. The Foyer-Halliwell-Asada cycle fundamentally relies on the oxidation and reduction of which non-enzymatic molecule?
(A) Ascorbate
(B) Alpha-tocopherol
(C) Carotene
(D) Salicylic acid

2004

116. Which term describes the biological consequence (internal change) resulting from applied environmental stress?
(A) Stimulus
(B) Strain
(C) Acclimation
(D) Adaptation

2009

117. What is the relationship between water potential, solute potential, and turgor pressure at the point of incipient plasmolysis?
(A) Pressure potential is zero; Water potential equals Solute potential.
(B) Water potential is zero; Solute potential equals Pressure potential.
(C) Solute potential is zero; Water potential equals Pressure potential.
(D) All three components are strictly zero.

2014

118. Identify the correct statement about micrometeorological factors affecting transpiration.
(A) High relative humidity steepens the leaf-to-air vapor pressure gradient.
(B) Still air conditions minimize the boundary layer resistance.
(C) Increased net radiation directly drives higher transpiration rates.
(D) Trichomes significantly decrease boundary layer thickness.

2001

119. Identify the INCORRECT statement regarding guard cell behavior.
(A) Swelling of guard cells opens the stoma.
(B) Radial micellation of cellulose microfibrils dictates the shape change.
(C) Guard cells lack chloroplasts entirely.
(D) Water influx is driven by a decrease in solute potential.

2009

120. Which of the following is a correct pair?
(A) WUE – Ratio of biomass produced to water transpired
(B) Harvest Index – Total transpired water
(C) Passioura's Model – Excludes harvest index
(D) Biomass – Irrelevant to yield models

2019

121. Which of the following is an INCORRECT pair regarding drought response?
(A) Deep rooting – Dehydration avoidance
(B) Rapid life cycle – Drought escape
(C) Osmotic adjustment – Dehydration tolerance
(D) Complete desiccation survival – Drought escape

2014

122. All of the following enzymes are directly involved in osmoprotectant biosynthesis EXCEPT:
(A) Pyrroline-5-carboxylate synthetase (P5CS)
(B) Nitrogenase
(C) Betaine aldehyde dehydrogenase (BADH)
(D) Trehalose-6-phosphate synthase (TPS)

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2009

123. What is the most appropriate structural classification for LEA proteins?
(A) Intrinsically disordered proteins
(B) Highly structured globular proteins
(C) Integral trans-membrane proteins
(D) Rigid cytoskeletal fibers

2025

124. The primary physiological trigger for aerenchyma formation during waterlogging is the accumulation of:
(A) Ethylene
(B) ABA
(C) Cytokinin
(D) Salicylic acid

2013

125. The survival of freezing temperatures in cold-acclimated plants is critically dependent on:
(A) Extracellular ice nucleation
(B) Intracellular ice formation
(C) Complete water loss from the plant
(D) Sudden membrane phase transitions

2024

102. Chilling injury primarily affects plants originating from which geographical regions?
(A) Alpine zones
(B) Tropical and subtropical zones
(C) Tundra
(D) Boreal forests

2004

103. Based on molecular function, what inference can be drawn if a plant heavily upregulates HSP70 during heat stress?
(A) It is actively preventing protein aggregation.
(B) It is synthesizing de novo lipids.
(C) It is repairing DNA double-strand breaks.
(D) It is closing aquaporins.

2024

104. The primary mechanism of photoinhibition involves damage to:
(A) The CF1 complex of ATP synthase
(B) Rubisco activase
(C) The D1 protein of the PSII reaction center
(D) Cytochrome f

2013

105. A major advantage of the xanthophyll cycle is its ability to:
(A) Synthesize novel and protective photopigments
(B) Fixing atmospheric nitrogen in chloroplast stroma
(C) Preventing all stomatal closure during light stress
(D) Quenching chlorophyll triplets and singlet oxygen

2018

106. Which term accurately classifies the specific morphological adaptation of elongated stems and reduced leaf area in dense canopies?
(A) Phototropism
(B) Gravitropism
(C) Shade Avoidance Syndrome
(D) Etiolation

2017

107. What is the immediate trigger for the osmotic phase of salinity stress?
(A) Toxic accumulation of sodium in older leaves
(B) Reduced water potential of the soil solution
(C) Direct chloride toxicity in the shoot apex
(D) Immediate destruction of root Casparian strips

2024

108. Identify the correct statement regarding ion compartmentalization under salinity stress.
(A) Potassium is entirely pumped out of the cell.
(B) Sodium is stored exclusively in chloroplasts.
(C) Vacuolar compartmentalization eliminates the need for osmotic adjustment.
(D) Sodium is sequestered into the vacuole to lower cytosolic toxicity.

2017

109. Identify the INCORRECT statement regarding heavy metal toxicity.
(A) Aluminum toxicity is most severe in highly acidic soils ($pH < 5.0$).
(B) Cadmium can induce oxidative stress.
(C) Heavy metals can displace essential cofactors in enzymes.
(D) Phytochelatins are crucial for heavy metal tolerance.

2004

110. Which of the following is a correct pair?
(A) Phytochelatins – Ribosomally synthesized strictly
(B) Metallothioneins – Gene-encoded peptides
(C) Vacuolar sequestration – Driven by simple diffusion
(D) Cadmium – Essential micronutrient

2019

111. Which of the following is an INCORRECT pair regarding ABA signaling?
(A) PP2C – Positive regulator of ABA signaling
(B) PYR/PYL – ABA receptor
(C) SnRK2 – Protein kinase
(D) SLAC1 – Anion channel

NODIA

2005

112. All of the following are classic physiological effects of cytokinins under stress EXCEPT:
(A) Maintenance of source-sink relationships
(B) Delay of leaf senescence
(C) Scavenging of some reactive oxygen species
(D) Immediate induction of rapid leaf abscission

2002

113. What is the most appropriate description of oxidative stress?
(A) Imbalance where ROS exceeds scavenging
(B) Antioxidant capacity exceeding production
(C) Complete removal of all cellular oxygen
(D) Exclusive singlet oxygen accumulation

(C) GID1
(D) ETR1

2006

66. Identify the correct statement regarding cytokinin function under abiotic stress.
(A) Cytokinin universally acts as a positive stress signal.
(B) Elevated cytokinin levels typically induce early senescence.
(C) Cytokinin overproduction often delays stress-induced leaf senescence.
(D) Cytokinin directly inhibits the SOS pathway.

2011

67. Which statement INCORRECTLY describes Reactive Oxygen Species (ROS) during oxidative stress?
(A) ROS serve as crucial signaling molecules at low concentrations.
(B) ROS are only produced under stress conditions.
(C) The superoxide radical is a primary precursor for other ROS.
(D) ROS can cause severe lipid peroxidation.

2007

68. Which of the following is a correct pair of an enzyme and its primary subcellular location?
(A) Superoxide Dismutase – Cytosol only
(B) Ascorbate Peroxidase – Vacuole
(C) Glutathione Reductase – Cell wall
(D) Catalase – Peroxisomes

2007

69. Which of the following is an INCORRECT pair regarding the Foyer-Halliwell-Asada cycle?
(A) Ascorbate – Antioxidant
(B) Hydrogen peroxide – Substrate
(C) Monodehydroascorbate reductase – Uses NADH/NADPH
(D) Glutathione – Radical generator

2019

70. All of the following are purely physical concepts applied to plant stress EXCEPT:
(A) Elastic modulus
(B) Plastic strain
(C) Yield point
(D) Signal transduction

2024

71. What is the most appropriate explanation for water potential being negative in living plant cells?
(A) Turgor pressure is always negative.
(B) Matric forces repel water molecules.
(C) Pure water has a water potential of -1 MPa.
(D) Solutes lower the free energy of water.

2014

72. Stomatal closure in response to high temperature primarily limits:
(A) Root water uptake
(B) Soil heat flux
(C) Mitochondrial respiration
(D) Transpirational cooling

2014

73. High Vapor Pressure Deficit (VPD) causes stomata to close by:
(A) Modifying guard cell turgor via passive hydraulic feedback
(B) Decreasing the transpiration stream directly
(C) Increasing internal CO_2 concentration
(D) Denaturing guard cell membrane proteins

2022

74. Plants can theoretically maximize yield under drought by:
(A) Minimizing Harvest Index
(B) Reducing Transpiration Efficiency
(C) Decreasing Water Use Efficiency
(D) Maximizing early soil water capture

2007

75. Compared to dehydration tolerance, drought escape is fundamentally categorized as:
(A) A phenological adjustment
(B) A biochemical defense
(C) A biophysical cellular modification
(D) An anatomical restructuring

2014

76. The accumulation of glycine betaine primarily serves to:
(A) Protect the oxygen-evolving complex of PSII
(B) Destabilize quaternary protein structures
(C) Increase cellular osmotic potential
(D) Induce leaf abscission

2017

77. What can be inferred about the widespread presence of LEA proteins in completely different kingdoms (plants, nematodes, bacteria)?
(A) Fundamental biological desiccation mechanism
(B) Evolved strictly for high heat tolerance
(C) Exclusively required for seed germination
(D) Diverse and specific enzymatic functions

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2019

126. A major advantage of accumulating Heat Shock Proteins (HSPs) is:
(A) They prevent the irreversible aggregation of heat-denatured proteins.
(B) They repair damaged cell walls.
(C) They actively cool the leaf surface.
(D) They generate ATP under heat stress.

2019

127. Which term describes the process where excess light energy damages the photosynthetic apparatus?
(A) Photoinhibition
(B) Phototropism
(C) Photomorphogenesis
(D) Photoperiodism

2019

128. What is the location of the xanthophyll cycle enzymes within the chloroplast?
(A) Stroma
(B) Outer envelope
(C) Lumen strictly
(D) Thylakoid membrane

2022

129. Identify the correct statement regarding phytochrome action under a canopy.
(A) Far-Red light converts the active Pfr form back to the inactive Pr form.
(B) Canopy shade is rich in Red light.
(C) Phytochrome exclusively regulates root growth.
(D) A high R:FR ratio strongly induces the Shade Avoidance Syndrome.

2001

130. Identify the INCORRECT statement about salinity stress.
(A) Halophytes require some salt for optimal growth.
(B) Glycophytes possess mechanisms to exclude salt, but have lower tolerance limits.
(C) High sodium competitively inhibits potassium uptake.
(D) The ionic phase strictly precedes the osmotic phase.

2024

131. Which of the following is a correct pair regarding the SOS pathway?
(A) SOS3 – Calcium sensor
(B) SOS1 – Kinase
(C) SOS2 – Transporter
(D) Calcium – Direct antiporter

NODIA

2021

132. Which of the following is an INCORRECT pair regarding heavy metal toxicity?
(A) Aluminum – Root apex inhibition
(B) Lead – Highly mobile in phloem
(C) Cadmium – Oxidative stress
(D) Arsenic – Phosphate mimicry

2012

133. All of the following are components of the heavy metal detoxification pathway EXCEPT:
(A) Glutathione (GSH)
(B) Phytochelatin synthase
(C) ATP-binding cassette (ABC) transporters
(D) Phytochrome interacting factors (PIFs)

2014

134. What is the function of the PYR/PYL/RCAR protein complex?
(A) Soluble ABA receptors that inhibit PP2Cs
(B) ABA-responsive nuclear transcription factors
(C) Membrane-bound ABA transporters in the cell
(D) Enzymes that actively degrade cellular ABA

2022

135. Cytokinin application often counters stress-induced senescence by maintaining the expression of:
(A) Chlorophyll biosynthesis and photosynthetic genes
(B) Ethylene synthesis genes
(C) ABA receptor genes
(D) Leaf abscission zone genes

2022

136. The extreme toxicity of the hydroxyl radical is primarily due to:
(A) Its lack of any specific enzymatic scavenger
(B) Its very long half-life
(C) Its ability to cross multiple cell membranes
(D) Its exclusive generation in the dark

2005

137. Which term describes the specific enzymatic conversion of hydrogen peroxide into water and oxygen by CAT?
(A) Dismutation
(B) Hydrolysis
(C) Phosphorylation
(D) Decarboxylation

2008

138. Which of the following is the primary lipid-soluble antioxidant protecting thylakoid membranes from lipid peroxidation?

mitochondria.

2003

230. The primary advantage of the Foyer-Halliwell-Asada cycle is its ability to:
(A) Produce large amounts of ATP directly
(B) Detoxify peroxide and regenerate substrates
(C) Generate superoxide strictly for signaling
(D) Synthesize primary cell wall components

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sterols.
(D) They strictly operate in the apoplast.

2003

150. Identify the INCORRECT statement about Heat Shock Proteins (HSPs).
(A) Their expression is regulated by Heat Shock Factors (HSFs).
(B) They require ATP for their chaperone activity.
(C) They assist in protein folding.
(D) They are synthesized exclusively during heat stress.

2002

151. Which of the following is a correct pair regarding chloroplasts under high light?
(A) PSII – Primary site of D1 damage
(B) PSI – Sole producer of singlet oxygen
(C) Rubisco – Primary electron acceptor of PSII
(D) Plastoquinone – Final electron acceptor in PSI

2013

152. Which of the following is an INCORRECT pair regarding photoprotection?
(A) NPQ – Heat dissipation
(B) Violaxanthin de-epoxidase – Low lumen pH activated
(C) Zeaxanthin – Light harvesting complex structural component
(D) Xanthophyll cycle – Operates strictly in the dark

2014

153. All of the following are classic responses of the Shade Avoidance Syndrome (SAS) EXCEPT:
(A) Accelerated flowering
(B) Stem elongation
(C) Increased leaf thickness
(D) Upward leaf movement (hyponasty)

2024

154. What is the most appropriate physiological explanation for the secondary, ionic phase of salt stress?
(A) Gradual toxic accumulation of Na^+ and Cl^-
(B) Sudden and total loss of cellular turgor
(C) Immediate abscission of the root meristem
(D) Rapid synthesis of active gibberellins

2011

155. The NHX1 antiporter contributes to salt tolerance by:
(A) Transporting sodium from the cytosol into the vacuole
(B) Pumping sodium out of the root into the soil
(C) Excluding chloride from the xylem stream
(D) Synthesizing proline

2025

156. Aluminum-induced root apex damage restricts overall plant growth primarily by:
(A) Limiting water and nutrient uptake
(B) Enhancing rapid leaf senescence
(C) Directly inhibiting photosynthesis in shoots
(D) Stimulating excessive root hair growth

2005

157. Which term describes the final storage compartment for heavy metal-phytochelatin complexes?
(A) Nucleus
(B) Vacuole
(D) Mitochondrion

2023

158. What is the immediate biochemical consequence when ABA binds to the PYR/PYL receptor?
(A) Receptor binds and inhibits a PP2C
(B) Receptor translocates to the nucleus
(C) Receptor degrades via the proteasome
(D) Receptor phosphorylates SnRK2 directly

NODIA

2013

159. Identify the correct statement regarding the cross-talk between ABA and Cytokinin under stress.
(A) They act synergistically to promote stomatal closure.
(B) Cytokinin generally antagonizes ABA-induced stress responses.
(C) ABA promotes cytokinin biosynthesis in roots.
(D) They strictly share the exact same receptor proteins.

2022

160. Identify the INCORRECT statement about ROS generation.
(A) ROS can act as secondary messengers in cellular signaling.
(B) The Mehler reaction is a major source of superoxide in chloroplasts.
(C) Photorespiration generates hydrogen peroxide in peroxisomes.
(D) Singlet oxygen is primarily generated during normal mitochondrial respiration.

2003

161. Which of the following is a correct pair regarding antioxidant enzymes?

(A) Alpha-tocopherol prevents the chain reaction of lipid peroxidation.
(B) Ascorbate is the primary lipid-soluble antioxidant in membranes.
(C) They are exclusively localized in the cell wall.
(D) They generate singlet oxygen to protect membranes.

2017

209. Identify the INCORRECT statement regarding plant strain and deformation.
(A) Biological yield point is exactly analogous to a pure mechanical yield point.
(B) Plastic strain implies permanent molecular or structural rearrangement.
(C) Mild stresses generally induce reversible elastic strain.
(D) Eustress represents a severe, permanently damaging stress.

2002

210. Which of the following is a correct pair regarding cellular water relations?
(A) Matric potential – Significant in dry seeds
(B) Pure water potential – -10 MPa
(C) Pressure potential – Always negative in living cells
(D) Solute potential – Always positive

2002

211. Which of the following is an INCORRECT pair regarding canopies?
(A) High leaf temperature – Increased sensible heat flux
(B) Stomatal closure – Reduced latent heat flux
(C) High transpiration – Increased latent heat flux
(D) Thick boundary layer – Increased transpiration rate

2022

212. All of the following directly induce stomatal closure EXCEPT:
(A) High VPD
(B) High internal CO_2 concentration
(C) High intensity blue light
(D) Exogenous ABA application

2009

213. What is the physiological interpretation of a high Water Use Efficiency (WUE) trait in a crop?
(A) The crop maximizes carbon assimilation per unit of water transpired.
(B) The crop strictly minimizes all photosynthesis.
(C) The crop has an extremely shallow root system.
(D) The crop completely lacks epicuticular waxes.

2024

214. The primary physiological distinction between drought escape and dehydration avoidance is:
(A) Escape involves accelerated phenology; avoidance maintains hydration.
(B) Escape strictly relies on LEA proteins.
(C) Avoidance involves completing the life cycle rapidly.
(D) There is absolutely no physiological difference.

2018

215. The synthesis of massive amounts of proline under drought stress primarily functions to:
(A) Maintain cell turgor and stabilize protein structures
(B) Repel herbivores
(C) Deplete cellular nitrogen reserves safely
(D) Act as the main structural component of the cell wall

2012

216. Which term classifies the highly conserved structural motif (EKKGIMDKIKEKLPG) characteristic of Dehydrins?
(A) K-segment
(B) Y-segment
(C) S-segment
(D) J-domain

2001

217. What is the primary metabolic shift in roots enduring prolonged soil waterlogging?
(A) Shift from aerobic respiration to lactic/ethanolic fermentation
(B) Shift from photosynthesis to purely photorespiration
(C) Shift from glycolysis directly to the Calvin cycle
(D) Complete cessation of all metabolic activity strictly

2018

218. Identify the correct statement about ice nucleation during freezing stress.
(A) Specialized ice nucleating active (INA) bacteria can promote extracellular freezing.
(B) Intracellular ice formation is generally well-tolerated by plant cells.
(C) Extracellular ice formation increases the hydration of the cytosol.

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lipid and lipid-protein interactions
(B) Massive accumulation of saturated fatty acids
(C) Immediate freezing of cytosolic water
(D) Rigidity of the cell wall cellulose network

2006

174. The degradation of the D1 protein during photoinhibition is primarily executed by which specific protease?
(A) Papain
(B) FtsH protease
(C) Caspase
(D) Subtilisin

2011

175. During prolonged high light stress, the steady-state level of which xanthophyll cycle pigment increases dramatically?
(A) Violaxanthin
(B) Antheraxanthin
(C) Lutein
(D) Zeaxanthin

2002

176. Which term describes the phytochrome-mediated physiological response ensuring seedling survival upon emergence from soil?
(A) Photomorphogenesis
(B) Etiolation
(C) Skotomorphogenesis
(D) Gravitropism

2015

177. What is the immediate primary effect of soil salinity on a non-halophytic plant?
(A) Physiological drought due to lowered soil water potential
(B) Immediate death of all meristems due to chlorine toxicity
(C) Rapid synthesis of heavy metal chelators
(D) Explosive lateral root growth

2018

178. Identify the correct statement regarding the mechanism of SOS1.
(A) It utilizes the proton gradient established by the plasma membrane H^+-ATPase to extrude sodium.
(B) It actively imports sodium into the cytosol.
(C) It acts as a calcium channel.
(D) It strictly localizes to the tonoplast.

2022

179. Identify the INCORRECT statement about Aluminum toxicity.
(A) It is a major agricultural problem in highly acidic soils ($pH < 5.0$).
(B) It restricts root elongation within hours of exposure.
(C) Aluminum tolerance is often achieved by organic acid exudation from roots.
(D) Aluminum strictly enhances phosphorus availability.

2002

180. Which of the following is a correct pair regarding heavy metal detoxification?
(A) Citrate/Malate exudation – Aluminum exclusion mechanism
(B) Phytochelatins – Ribosomally synthesized strictly
(C) Metallothioneins – Enzymatically synthesized strictly
(D) Cadmium – Essential micronutrient

2010

181. Which of the following is an INCORRECT pair regarding the ABA signaling core pathway?
(A) PYR/PYL – Soluble receptor
(B) PP2C – Kinase
(C) SnRK2 – Positive regulator
(D) AREB/ABF – Transcription factor

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2018

182. All of the following represent typical roles of cytokinins under stress EXCEPT:
(A) Regulation of the cell cycle
(B) Delay of stress-induced senescence
(C) Modulation of source-sink dynamics
(D) Primary mediator of rapid stomatal closure

2014

183. What is the biological role of the hydroxyl radical in plants?
(A) It is a universally destructive ROS causing indiscriminate cellular damage.
(B) It serves as a highly specific, controlled signaling molecule.
(C) It is the primary electron acceptor in PSI.
(D) It strictly facilitates ATP synthesis.

2007

184. The enzyme responsible for converting hydrogen peroxide to water using ascorbate as an electron donor is:
(A) Ascorbate Peroxidase
(B) Superoxide Dismutase
(C) Catalase
(D) Glutathione Reductase

(A) Alpha-tocopherol
(B) Ascorbate
(C) Glutathione
(D) Proline

2011

139. Identify the correct statement regarding plastic deformation in plant mechanics.
(A) It results in irreversible structural changes or damage.
(B) It strictly occurs before the yield threshold is reached.
(C) It is a completely reversible process.
(D) It is synonymous with eustress.

2004

140. Identify the INCORRECT statement about cellular water potential.
(A) Water flows from higher to lower water potential.
(B) Solute potential in mature cells is determined largely by vacuolar contents.
(C) Turgor pressure can drop to zero during severe dehydration.
(D) Matric potential is the dominant component in fully hydrated mature leaves.

2015

141. Which of the following is a correct pair regarding plant canopies?
(A) Latent heat flux – Energy used for transpiration
(B) Sensible heat flux – Energy used for photosynthesis
(C) Net radiation – Reflected solar energy strictly
(D) Boundary layer – Independent of leaf morphology

2002

142. Which of the following is an INCORRECT pair regarding stomatal mechanics?
(A) Stomatal opening – Potassium influx
(B) Stomatal closure – Malate efflux/degradation
(C) Stomatal opening – ABA synthesis
(D) Stomatal closure – High VPD

2018

143. All of the following can physiologically increase Water Use Efficiency (WUE) EXCEPT:
(A) Partial stomatal closure
(B) Decreased boundary layer resistance via small leaf size
(C) Enhanced mesophyll conductance for CO_2
(D) Maximized cuticular transpiration

2005

144. What is the most appropriate description of osmotic adjustment?
(A) Active net accumulation of solutes to lower osmotic potential.
(B) Passive concentration of solutes purely due to water loss.
(C) Immediate loss of turgor upon stress perception.
(D) Extrusion of all cellular potassium.

2023

145. The accumulation of compatible solutes provides a massive advantage over simple inorganic ion accumulation because:
(A) They do not disrupt enzymes at high levels
(B) They require zero metabolic energy to form
(C) They immediately trigger rapid leaf abscission
(D) They directly replace water in the cell wall

2009

146. A primary structural feature of dehydrins is the presence of:
(A) Highly conserved K-segments
(B) Cysteine-rich heavy metal binding domains
(C) Transmembrane alpha-helices
(D) Active kinase domains

2024

147. Which term describes the programmed cell death process leading to aerenchyma formation?
(A) Lysigeny
(B) Necrosis
(C) Schizogeny
(D) Plasmolysis

2022

148. What is the primary mechanism by which plants prevent intracellular freezing?
(A) Synthesizing antifreeze proteins and promoting extracellular ice nucleation
(B) Accumulating ice nucleators inside the cytoplasm
(C) Pumping all cellular water into the roots
(D) Rapidly degrading all membrane lipids

2002

149. Identify the correct statement regarding the role of membrane lipid desaturases during cold acclimation.
(A) They introduce double bonds into fatty acids to maintain fluidity.
(B) They remove double bonds to increase membrane rigidity.
(C) They convert phospholipids directly into

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(A) Molecular chaperones
(B) The proteasome
(C) Ubiquitin ligases
(D) Nucleosomes

2021

197. What is the immediate biochemical source of singlet oxygen during high light stress?
(A) Energy transfer to ground state oxygen
(B) Direct reduction of superoxide radical
(C) Spontaneous hydrogen peroxide breakdown
(D) Direct reduction of water molecules

2001

198. Identify the correct statement regarding Non-Photochemical Quenching (NPQ).
(A) It relies on the PsbS protein and the xanthophyll cycle to dissipate heat.
(B) It is fully independent of the proton gradient across the thylakoid membrane.
(C) It actively increases the quantum yield of PSII.
(D) It occurs primarily in the stroma.

2003

199. Identify the INCORRECT statement about the red/far-red light responses.
(A) A high R:FR ratio indicates full sunlight.
(B) Shade from neighboring plants drastically lowers the R:FR ratio.
(C) PIF transcription factors are crucial for shade avoidance responses.
(D) Phytochromes strictly exist as a single, non-convertible isoform.

2006

200. Which of the following is a correct pair regarding salinity?
(A) Halophyte – Requires or optimally tolerates high salt
(B) Glycophyte – Highly tolerant to salt
(C) Osmotic stress – The long-term, delayed phase of salinity
(D) Ionic stress – Immediate, non-specific response

2013

201. Which of the following is an INCORRECT pair regarding the SOS signaling pathway?
(A) Salt stress stimulus – Increases cytosolic calcium
(B) SOS3 – Binds calcium
(C) SOS1 – Extrudes sodium
(D) SOS2 – Dephosphorylates strictly

2004

202. All of the following are recognized mechanisms of heavy metal tolerance EXCEPT:
(A) Exclusion of the metal at the root surface
(B) Complexation with organic acids in the apoplast
(C) Sequestration into the vacuole
(D) Deliberate concentration of heavy metals strictly in the nucleus

2014

203. What is the biochemical function of phytochelatin synthase?
(A) Polymerizes glutathione upon activation
(B) Synthesizes strictly from amino acids
(C) Actively degrades phytochelatin in vacuoles
(D) Transports metals across the membrane

2014

204. The rapid dephosphorylation and activation of SnRK2 kinases under drought stress directly relies on the inhibition of:
(A) PP2C phosphatases
(B) PYR/PYL receptors
(C) ABF transcription factors
(D) Calcium channels

2021

205. A significant consequence of localized cytokinin degradation during severe stress is:
(A) Acceleration of source-leaf senescence to remobilize nutrients
(B) Indefinite extension of the leaf lifespan
(C) Complete cessation of root growth
(D) Prevention of any ABA synthesis

2012

206. Which term describes the localized specific cellular site where the Mehler reaction generates superoxide?
(A) Photosystem I
(B) Photosystem II
(C) Cytochrome b6f
(D) Light Harvesting Complex

2022

207. What metallic cofactor is present in the active site of the most common cytosolic Superoxide Dismutase (SOD) in plants?
(A) Copper and Zinc
(B) Iron
(C) Manganese
(D) Nickel

2018

208. Identify the correct statement regarding lipid-soluble antioxidants.

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2015

185. A significant advantage of the Ascorbate-Glutathione cycle over Catalase is:
(A) Scavenging ROS in multiple compartments
(B) Operating primarily in the cell wall
(C) Requiring absolutely no metabolic energy
(D) Functioning perfectly without any enzymes

2005

186. Which term describes the initial, fully reversible phase of plant response to an applied abiotic stressor?
(A) Alarm phase (Elastic strain)
(B) Exhaustion phase (Plastic strain)
(C) Yield point
(D) Senescence

2001

187. What is the effect of active solute accumulation on cellular water potential components?
(A) Decreases solute potential and allows maintenance of turgor
(B) Increases solute potential and decreases pressure potential
(C) Strictly increases matric potential
(D) Immediately reduces turgor to zero

2019

188. Identify the correct statement regarding latent heat flux.
(A) It represents the energy consumed to evaporate water during transpiration.
(B) It refers to the heat lost strictly through long-wave radiation.
(C) It is the energy strictly stored in chemical bonds during photosynthesis.
(D) It decreases as transpiration increases.

2016

189. Which of the following INCORRECTLY describes the response of guard cells to ABA?
(A) ABA triggers an increase in cytosolic calcium.
(B) ABA promotes the activation of anion channels (e.g., SLAC1).
(C) ABA activates inward-rectifying potassium channels (e.g., KAT1).
(D) ABA promotes the efflux of potassium and malate ions.

2018

190. Which of the following is a correct pair regarding water use?
(A) Water Use Efficiency – Defined as yield per unit water transpired
(B) Passioura's Model – Irrelevant for breeding under drought
(C) Stomatal conductance – Strictly independent of WUE
(D) Epicuticular wax – Increases cuticular transpiration

2008

191. Which of the following is an INCORRECT pair regarding drought response?
(A) Drought escape – Phenological adaptation
(B) Dehydration avoidance – Maintaining tissue hydration
(C) Dehydration tolerance – Tissue survival at low water potential
(D) Osmotic adjustment – Strictly a drought escape mechanism

2015

192. All of the following are biochemical characteristics of effective compatible solutes EXCEPT:
(A) High and stable solubility in aqueous media
(B) Absence of net charge at physiological pH levels
(C) Non-inhibitory to enzymes at high concentrations
(D) Strong hydrophobic properties causing precipitation

2010

193. What is the physical state of LEA proteins in completely dry seeds?
(A) Fold into helices to stabilize membranes
(B) Remain fully disordered and randomized
(C) Form rigid, insoluble crystal aggregates
(D) Are completely degraded into amino acids

2010

194. The anatomical formation of aerenchyma involves the deliberate breakdown of specific cells in the:
(A) Root cortex
(B) Epidermis
(C) Endodermis
(D) Xylem vessels

2022

195. The primary advantage of extracellular ice nucleation during freezing stress is:
(A) Lowers internal freezing to prevent ice
(B) Freezes the cytosol to suspend metabolism
(C) Breaks the cell wall to allow expansion
(D) Prevents any form of dehydration stress

2022

196. Which term describes the complex of proteins, including HSPs, that refolds denatured proteins during heat stress?

(D) Ice strictly forms inside the nucleus first.

2010

219. Identify the INCORRECT statement regarding heat stress.
(A) HSPs act as irreversible inhibitors of cellular metabolism.
(B) Heat stress increases the kinetic energy of membrane lipids.
(C) Heat severely damages the oxygen-evolving complex of PSII.
(D) Acquired thermotolerance requires de novo protein synthesis.

2011

220. Which of the following is a correct pair regarding high light stress?
(A) D1 protein – Rapidly degraded and resynthesized
(B) Photo-oxidation – Strictly beneficial for photosynthesis
(C) Singlet oxygen – Formed in the dark
(D) Photoinhibition – Enhances overall carbon fixation

2018

221. Which of the following is an INCORRECT pair regarding photoprotection?
(A) Violaxanthin – Diepoxide xanthophyll
(B) Zeaxanthin – Epoxide-free xanthophyll
(C) NPQ – Non-photochemical quenching
(D) PsbS – Active protease degrading D1

2008

222. All of the following represent components of the low light shade avoidance response EXCEPT:
(A) Stem and petiole elongation responses
(B) Significant increase in specific leaf area
(C) Accelerated and premature flowering onset
(D) Massive accumulation of thick cuticular wax

2016

223. What is the most appropriate description of the ionic phase of salinity stress?
(A) It is driven by the gradual, toxic accumulation of Na^+ and Cl^- inside plant cells over time.
(B) It strictly occurs within seconds of salt exposure.
(C) It is entirely resolved by immediate osmotic adjustment.
(D) It only affects the root epidermal cells.

2003

224. The SOS2-SOS3 complex is directly responsible for:
(A) Phosphorylating and activating the SOS1 Na^+/H^+ antiporter
(B) Synthesizing cyclic AMP
(C) Degrading the tonoplast
(D) Transporting calcium into the nucleus

2021

225. A significant consequence of Aluminum interference with cellular metabolism in roots is:
(A) Alteration of root cytoskeleton and inhibition of elongation
(B) Immediate induction of rapid cell division
(C) Exponential increase in lateral root formation
(D) Enhanced uptake of calcium and magnesium

2014

226. Which term describes the final inactive complex formed when phytochelatins bind heavy metals and move into the vacuole?
(A) LMW transitioning to HMW complexes
(B) A purely gaseous metallic state
(C) A solid crystalline lattice
(D) An active metalloenzyme

2018

227. What is the immediate result of PP2C phosphatase inhibition by the PYR/PYL/ABA complex?
(A) SnRK2 kinases are freed from inhibition and become auto-phosphorylated/active.
(B) SnRK2 kinases are immediately degraded.
(C) Stomata forcefully open.
(D) ABA synthesis completely stops.

2004

228. Identify the correct statement regarding cytokinin dynamics under stress.
(A) Stress-induced reduction in cytokinin levels facilitates nutrient remobilization during senescence.
(B) Cytokinin overproduction typically accelerates plant death during drought.
(C) Cytokinin and ABA have highly synergistic effects on stomatal movement.
(D) Cytokinin strictly acts in roots and never in shoots.

2022

229. Identify the INCORRECT statement regarding Reactive Oxygen Species.
(A) Low levels of hydrogen peroxide act as essential stress signals.
(B) Highly toxic hydroxyl radicals cannot be enzymatically scavenged.
(C) Singlet oxygen is formed via energy transfer from triplet chlorophyll.
(D) Superoxide is exclusively formed in the

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(A) SOD – Requires metal cofactors (Cu, Zn, Mn, Fe)
(B) CAT – Heavily reliant on NADPH
(C) APX – Operates without any reductant
(D) GR – Generates hydrogen peroxide

2024

162. Which of the following is an INCORRECT pair regarding the Ascorbate-Glutathione cycle?
(A) Ascorbate – Primary electron donor for APX
(B) Monodehydroascorbate – Readily converted back to ascorbate
(C) Glutathione disulfide (GSSG) – The active, reduced form of glutathione
(D) Glutathione Reductase – Utilizes NADPH

2007

163. All of the following physiological factors influence plant elastic strain EXCEPT:
(A) Cell wall composition
(B) Turgor pressure
(C) Complete nuclear degradation
(D) Cytoskeletal integrity

2005

164. What is the most appropriate consequence of a severely negative matric potential in dry soils?
(A) Water is held tightly to soil particles, reducing availability.
(B) Water is easily absorbed by plant roots.
(C) Solute potential becomes strongly positive.
(D) Root pressure increases exponentially.

2025

165. The energy balance equation implies that if net radiation remains constant but stomata close:
(A) Sensible heat flux and leaf temperature must increase.
(B) Latent heat flux increases.
(C) Photosynthesis accelerates.
(D) Soil heat flux becomes strictly zero.

2018

166. Which term describes the guard cell membrane transporter primarily responsible for the rapid efflux of anions during stomatal closure?
(A) SLAC1
(B) AHA1 (H^+-ATPase)
(C) PIP2 (Aquaporin)
(D) KAT1 (K^+ channel)

2010

167. What is the primary utility of Passioura's Yield Model in agricultural research?
(A) Framework for targeting specific traits
(B) Predicting heavy metal accumulation rates
(C) Determining genetic sequences of proteins
(D) Calculating precise rates of inhibition

2018

168. Identify the correct statement regarding dehydration avoidance.
(A) Traits like deep rooting and cuticular waxes are typical mechanisms.
(B) It involves complete cellular desiccation and survival.
(C) It strictly requires the expression of heat shock factors.
(D) It is only observed in resurrection plants.

2023

169. Identify the INCORRECT statement regarding trehalose in stressed plants.
(A) It is a non-reducing disaccharide.
(B) It functions effectively as a compatible solute.
(C) Trehalose-6-phosphate also acts as a crucial signaling molecule.
(D) It is primarily toxic and rapidly degraded under stress.

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2017

170. Which of the following is a correct pair?
(A) Dehydrins – Group II LEA proteins
(B) LEA Proteins – Synthesized mainly during vegetative rapid growth
(C) LEA Proteins – Highly hydrophobic
(D) Dehydrins – Catalyze protein degradation

2025

171. Which of the following is an INCORRECT pair regarding hypoxia/anoxia?
(A) Hypoxia – Partial oxygen deficiency
(B) Anoxia – Complete lack of oxygen
(C) Fermentation – Highly efficient ATP production
(D) Aerenchyma – Facilitates oxygen transport

2004

172. All of the following occur during chilling injury in susceptible plants EXCEPT:
(A) Phase transition of membranes from liquid-crystalline to solid-gel
(B) Increased leakage of cellular solutes
(C) Accumulation of reactive oxygen species
(D) Enhanced efficiency of the photosynthetic electron transport chain

2012

173. What is the structural reason for heat-induced membrane hyper-fluidity?
(A) Increased kinetic energy destabilizing lipid-

ANSWERS

1. (B) Elastic strain
Elastic strain describes the temporary and fully reversible physical deformation of plant tissues in response to environmental stressors. When the stress is removed, the tissue returns to its original state without permanent structural damage. This process contrasts with plastic strain, which involves irreversible alterations to the plant's structure and can lead to permanent growth reductions.

2. (C) I only
Solute potential is universally negative in living cells because the presence of dissolved substances reduces the free energy of water compared to pure water. Pressure potential is typically positive in fully turgid cells due to the internal force against the cell wall. Matric potential, which results from water adhering to surfaces, is always negative and never positive.

3. (D) Dense trichome presence
Boundary layer resistance is primarily influenced by the physical characteristics of the leaf surface and the surrounding air movement. Dense trichomes or leaf hairs create a thicker layer of still air at the leaf surface, effectively increasing the resistance to gas exchange and water vapor loss. Higher wind speeds or low canopy density generally reduce the thickness of this layer.

4. (A) P-2, Q-1, R-3, S-4
Stomatal behavior is regulated by complex environmental and hormonal triggers. High vapor pressure deficit causes closure to conserve water, while blue light induces opening through proton pump activation. Abscisic acid accumulation leads to the efflux of ions like potassium from guard cells, facilitating closure. Malate synthesis is a key metabolic process during turgor-driven stomatal opening to balance cation charges.

5. (B) Enhanced mesophyll conductance
In the Passioura yield model, transpiration efficiency is defined as the amount of carbon fixed per unit of water transpired. Enhancing mesophyll conductance allows more carbon dioxide to reach the chloroplasts without increasing stomatal conductance. This physiological modification improves the ratio of photosynthesis to transpiration, thereby directly increasing water use efficiency and final crop yield under water-limited conditions.

6. (D) A is false but R is true.
Ephemeral desert plants utilize a strategy known as drought escape rather than dehydration tolerance. They adapt to arid environments by rapidly completing their entire life cycle during brief periods of moisture availability. This allows them to produce seeds and die before severe soil water deficits occur, avoiding the need for cellular mechanisms to withstand extreme physiological dehydration.

7. (A) It acts as a compatible solute for osmotic adjustment.
Proline is a primary compatible solute that accumulates in the cytosol during osmotic stress to facilitate adjustment. By lowering the cellular osmotic potential, it helps maintain turgor and allows the plant to continue absorbing water from dry soils. Additionally, proline protects cellular structures and enzymes from damage without interfering with normal metabolic processes even when present at high concentrations.

8. (A) I and III
Late embryogenesis abundant proteins are characterized by their highly hydrophilic nature and lack of a strict three-dimensional structure in fully hydrated states. These intrinsically disordered proteins provide protection against desiccation by stabilizing cellular membranes and proteins during water loss. Unlike most proteins, they do not denature upon boiling and are not exclusively involved in heat stress responses but rather dehydration.

9. (D) Ethanol
Under prolonged anoxia or complete lack of oxygen, aerobic respiration is inhibited and plants switch to fermentative metabolism to maintain energy production. In submerged roots, ethanolic fermentation becomes the predominant pathway, leading to the accumulation of ethanol as the primary metabolic end-product. This process allows for the regeneration of NAD+

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apparatus and significant damage. If left unchecked, photo-oxidation can cause permanent tissue necrosis and limit survival.

82. (D) Photorespiration acting to protect PSII
Under high light stress, alternative electron sinks provide a way to dissipate excess excitation energy and prevent the over-reduction of the electron transport chain. Photorespiration is a key protective mechanism that consumes excess ATP and NADPH, thereby maintaining the flow of electrons and reducing the risk of damage to photosystem II. This process is essential for preventing the formation of reactive species.

83. (D) It is triggered by a high Red to Far-Red ratio.
Shade avoidance syndrome is a set of morphological adjustments that plants undergo to compete for light. Typical responses include increased stem elongation and an upward bending of leaves known as hyponasty. Contrary to incorrect claims, this syndrome is triggered by a low red to far-red ratio, which signals the presence of nearby competing plants. A high ratio indicates full sunlight.

84. (D) Osmotic phase – Immediate growth arrest
Salinity stress affects plants in two distinct phases. The osmotic phase occurs immediately upon exposure to salt, leading to a rapid reduction in water potential and a corresponding arrest in growth, which mirrors the effects of drought. The ionic phase is a more gradual process that involves the toxic accumulation of ions in leaves over time. Correct understanding highlights immediate growth reduction.

85. (A) NHX1 – Plasma membrane
The salt overly sensitive pathway involves several proteins with specific cellular locations and functions. SOS1 is a sodium-proton antiporter located on the plasma membrane, while SOS2 is a protein kinase and SOS3 is a calcium-binding protein. Contrary to incorrect pairings, NHX1 is a sodium-proton antiporter that is primarily located on the tonoplast or vacuolar membrane, functioning to sequester sodium ions.

86. (D) Enhanced root hair proliferation.
Aluminum toxicity in acidic soils results in several characteristic symptoms including callose deposition, root apex swelling, and the disruption of the root cytoskeleton. These effects collectively inhibit root elongation and impair the uptake of water and nutrients. Unlike responses to nutrient deficiencies, aluminum toxicity does not typically lead to enhanced root hair proliferation; instead, it causes general root stunting and meristem damage.

87. (D) To chelate metals via cysteine-rich domains
Metallothioneins are low-molecular-weight, cysteine-rich proteins that are encoded by specific genes and expressed in response to heavy metals. Their primary biological role is to chelate and detoxify toxic metal ions such as copper or zinc. By binding these metals through their abundant cysteine residues, metallothioneins prevent them from interacting with sensitive cellular components. This mechanism is essential for maintaining metal homeostasis.

88. (A) Plasma membrane anion channels (e.g., SLAC1)
Abscisic acid-induced stomatal closure is a complex process that relies on the activation of specific ion channels in the guard cell plasma membrane. Key among these are anion channels such as SLAC1, which allow for the efflux of negatively charged ions like chloride. This efflux causes membrane depolarization, which in turn triggers the opening of outward-rectifying potassium channels and turgor loss.

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89. (D) Delayed onset of senescence
The application of cytokinins to drought-stressed leaves generally results in a delayed onset of senescence. Cytokinins act as powerful inhibitors of the senescence program by maintaining chlorophyll levels and the expression of genes involved in photosynthesis. By preserving the metabolic activity of the leaf, cytokinins help the plant sustain its photosynthetic capacity. This hormonal intervention can counteract the effects of stress-induced abscisic acid.

90. (A) Hydroxyl radical
Among the various reactive oxygen species, the hydroxyl radical is considered the most highly reactive and destructive. It is capable of indiscriminately reacting with and damaging almost any biological molecule it encounters, including proteins and DNA. Unlike superoxide, there is no known specific enzymatic scavenger for the hydroxyl radical. Its extremely short half-life means it reacts immediately at its site of generation.

interfering with essential cellular and metabolic processes.

19. (D) Type 2C protein phosphatases (PP2Cs)
The core abscisic acid signaling pathway involves the binding of the hormone to PYR/PYL/RCAR receptors. This binding event triggers a conformational change that allows the receptor to interact with and inhibit type 2C protein phosphatases. The inhibition of these negative regulators releases SnRK2 kinases from repression, allowing them to activate downstream targets like ion channels and various transcription factors.

20. (B) I and III
Cytokinin molecules play a complex role in stress signaling, generally acting to delay rather than promote stress-induced leaf senescence. During drought, cytokinin levels typically decrease, which helps the plant remobilize nutrients from older tissues. Furthermore, cytokinins are often considered negative regulators of extreme cold tolerance, as high levels can interfere with the acclimation processes necessary for survival in freezing.

21. (B) Chloroplasts
The chloroplast is the primary site of singlet oxygen generation during high light stress due to its role in photosynthesis. When the absorption of light energy exceeds the capacity for carbon fixation, triplet state chlorophyll can react with ground-state oxygen to produce highly reactive singlet oxygen. This process occurs mainly within the photosystem II reaction centers and causes photo-oxidative damage.

22. (A) P-2, Q-1, R-4, S-3
Enzymatic antioxidants work systematically to detoxify different reactive species within the cell. Superoxide dismutase converts superoxide anions into hydrogen peroxide, which is then further neutralized. Catalase directly breaks down hydrogen peroxide into water and oxygen. Ascorbate peroxidase also targets hydrogen peroxide but utilizes ascorbate as a specific reductant, while glutathione S-transferase is involved in detoxifying lipid hydroperoxides.

23. (A) NADPH
The Foyer-Halliwell-Asada cycle is a crucial pathway for scavenging hydrogen peroxide in chloroplasts. In this cycle, ascorbate is oxidized while neutralizing peroxide and must be continuously regenerated. NADPH serves as the terminal electron donor, providing the necessary reducing power to convert oxidized glutathione and monodehydroascorbate back into their functional, reduced forms through the action of glutathione reductase and other enzymes.

24. (A) Both A and R are true and R is the correct explanation of A.
Severe abiotic stress can push plant tissues beyond their elastic limit, resulting in plastic deformation. This type of response is characterized by irreversible structural alterations or damage to cell walls and other cellular components. Unlike elastic strain, which is temporary and allows for full recovery, plastic deformation signifies a permanent change in the plant's form or function, leading to yield loss.

25. (D) Pressure potential
Pressure potential, also known as turgor pressure, is the physical force exerted by the cell contents against the cell wall. It is the primary component of water potential responsible for maintaining the rigidity and structural integrity of plant cells. High turgor pressure allows cells to expand and supports the overall mechanical strength of non-woody tissues, which is essential for growth.

26. (A) I and III
Energy balance in plant canopies is determined by the partitioning of incoming radiation. Transpiration is a vital cooling mechanism that transfers latent heat away from the leaf surface. The net radiation received by the canopy is balanced by the sum of sensible heat flux to the air, latent heat flux through evaporation, and heat conducted into the soil during daytime.

27. (B) Stomatal closure to prevent excessive water loss
A sudden increase in vapor pressure deficit represents a higher atmospheric demand for moisture, which can lead to excessive transpiration. Most mesophytic crops respond by closing their stomata to prevent dehydration and maintain cellular turgor. This rapid physiological adjustment is crucial for survival during periods of high evaporative demand, although it simultaneously limits the rate of carbon dioxide uptake for photosynthesis.

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64. (D) Phytochelatins
Phytochelatins are specialized peptides that play a central role in the detoxification of heavy metals within plant cells. They are synthesized enzymatically from glutathione by the enzyme phytochelatin synthase in response to the presence of metal ions. These peptides contain multiple cysteine residues that allow them to chelate toxic metals, forming stable complexes that are subsequently sequestered into the central vacuole.

65. (B) PYR/PYL/RCAR
The PYR/PYL/RCAR family of proteins serves as the primary cellular receptor complex for abscisic acid signaling. These soluble receptors bind directly to the hormone, which then allows them to interact with and inhibit type 2C protein phosphatases. This inhibition is the fundamental step that activates the downstream signaling cascade, leading to various stress responses such as stomatal closure and gene expression.

66. (C) Cytokinin overproduction often delays stress-induced leaf senescence.
Cytokinins generally function to delay the onset of leaf senescence induced by various abiotic stresses. While stress often leads to a decrease in endogenous cytokinin levels, the overproduction or exogenous application of these hormones can help maintain chlorophyll content and photosynthetic activity. This action helps the plant sustain growth and productivity for longer periods during adverse conditions, sustaining vital metabolic cellular pathways.

67. (B) ROS are only produced under stress conditions.
Reactive oxygen species are natural byproducts of aerobic metabolism and are produced under both normal and stress conditions. While their levels increase significantly during oxidative stress, they are constantly generated in organelles like chloroplasts and mitochondria during photosynthesis and respiration. At low concentrations, these molecules serve as vital signaling agents. However, excessive accumulation can lead to severe damage such as lipid peroxidation.

68. (D) Catalase – Peroxisomes
Antioxidant enzymes are strategically localized within various cellular compartments to manage reactive oxygen species. Catalase is specifically found in peroxisomes, where it neutralizes hydrogen peroxide generated during photorespiration and fatty acid breakdown. Other enzymes like superoxide dismutase are distributed across the cytosol and chloroplasts. The compartmentalization ensures that reactive species are detoxified near their primary sites of generation, protecting entire cells.

69. (D) Glutathione – Radical generator
The Foyer-Halliwell-Asada cycle utilizes several key components to scavenge hydrogen peroxide in plants. Ascorbate acts as a primary antioxidant and electron donor, while monodehydroascorbate reductase uses NADH or NADPH to regenerate the system. Contrary to incorrect claims, glutathione is a crucial antioxidant rather than a radical generator. It works in conjunction with enzymes to maintain reduced ascorbate, ensuring detoxification.

70. (D) Signal transduction
Many concepts from classical physics are applied to describe plant responses to stress. Elastic modulus, plastic strain, and yield point are all physical terms used to characterize how tissues deform under environmental pressure. In contrast, signal transduction is a purely biological process. It involves complex biochemical pathways through which cells perceive external stimuli and relay that information through molecular messengers to elicit responses.

71. (D) Solutes lower the free energy of water.
Water potential is typically negative in living plant cells because of the presence of solutes. According to thermodynamic laws, dissolving substances in water reduces its free energy and increases its entropy, thereby lowering its chemical potential compared to pure water. Since pure water is assigned a potential of zero, any solution will have a negative solute potential, contributing to a negative potential.

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72. (D) Transpirational cooling
Stomatal closure is a common response to extreme conditions, but it can have detrimental effects on leaf temperature. During periods of high temperature, closing the stomata significantly limits the rate of transpiration. This reduction in water vapor loss prevents the cooling effect of latent heat dissipation, which often results in a rapid increase in leaf temperature, potentially leading to protein denaturation.

37. (B) Phytochrome
Phytochromes are the primary photoreceptors responsible for perceiving changes in the ratio of red to far-red light within a plant canopy. These pigments exist in two interconvertible forms that respond to specific wavelengths, allowing the plant to detect the presence of neighboring vegetation. This light-sensing mechanism triggers developmental adjustments, such as stem elongation, to help the plant compete for sunlight.

38. (A) P-2, Q-1, R-4, S-3
Salinity stress impacts plants in distinct stages and through various adaptive mechanisms. The osmotic phase occurs rapidly, causing a water deficit and growth reduction similar to drought. The ionic phase develops more slowly as toxic ions accumulate in tissues. Tolerance strategies include exclusion at the roots to block ion entry and compartmentalization, where sodium is sequestered into the central vacuole.

39. (A) Calcium ions
The salt overly sensitive pathway is a fundamental mechanism for maintaining ion homeostasis under high salinity. This pathway relies on the intracellular sensing of calcium ions, which act as secondary messengers. An increase in cytosolic calcium is detected by the sensor protein SOS3, which then activates the SOS2 kinase. This signaling cascade ultimately leads to the activation of sodium exclusion mechanisms.

40. (A) II, I, IV, III
Heavy metal detoxification involves a series of coordinated steps starting with the entry of the metal into the cytosol. This presence activates the enzyme phytochelatin synthase, which produces phytochelatins from glutathione. These peptides then form complexes with the metal ions to neutralize their toxicity. Finally, the resulting metal-phytochelatin complex is sequestered into the central vacuole for safe, long-term cellular storage.

41. (D) Zinc
Cadmium is a highly toxic heavy metal that interferes with cellular metabolism by mimicking essential micronutrients. It primarily disrupts the function of vital metalloenzymes by replacing zinc as a cofactor in their active sites. Because cadmium cannot perform the same catalytic role as zinc, the affected enzymes become inactive, leading to widespread metabolic dysfunction and the inhibition of plant growth.

42. (C) A is true but R is false.
SnRK2 kinases are central positive regulators in the abscisic acid signaling pathway and are essential for mediating responses like stomatal closure. Under stress, these kinases are activated through phosphorylation rather than dephosphorylation. In the absence of stress, type 2C protein phosphatases keep SnRK2s inactive by removing their phosphate groups. When ABA is present, the phosphatases are inhibited, allowing kinases to remain active.

43. (B) Cytokinin
Cytokinins are phytohormones that fundamentally antagonize the senescence-promoting effects of various abiotic stresses. By maintaining chlorophyll levels and promoting the expression of photosynthetic genes, they delay the breakdown of cellular components in leaves. This action opposes the effects of stress-induced hormones like abscisic acid and ethylene, which typically trigger premature senescence and nutrient remobilization to help the plant cope.

44. (A) II, III and IV
Reactive oxygen species have varying properties and effects on cellular components. Hydrogen peroxide is uncharged and can cross membranes, acting as a signaling molecule. Incorrect statements suggest that the hydroxyl radical is the least reactive, whereas it is actually the most destructive. Additionally, superoxide is not a strong electrophile for DNA, and singlet oxygen is primarily formed through physical transfer.

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45. (A) Catalase
Catalase is a unique enzymatic antioxidant that directly converts hydrogen peroxide into water and oxygen without requiring any specific cellular reductant or electron donor. This high-capacity enzyme is primarily located in peroxisomes, where it efficiently neutralizes the large amounts of peroxide generated during photorespiration and fatty acid oxidation. Its ability to function independently of other substrates makes it a critical defense.

46. (A) Plasma membrane
Non-enzymatic scavenging systems involve both water-soluble and lipid-soluble antioxidants. Lipid-soluble antioxidants, such as alpha-

28. (A) P-2, Q-4, R-3, S-1
Improving water use efficiency involves various morphological and phenological strategies. Deep rooting allows plants to access water reserves in lower soil layers, while early maturity enables them to evade terminal drought by finishing their life cycle. Epicuticular waxes serve to reduce non-stomatal cuticular transpiration. Narrow leaves minimize the boundary layer resistance, which helps maintain a favorable leaf temperature and reduces loss.

29. (A) Maintaining high tissue water potential during drought
Dehydration avoidance is a strategy where plants maintain high tissue water potential despite environmental drought conditions. This is achieved through mechanisms that either enhance water uptake, such as deep root systems, or reduce water loss, such as stomatal closure and specialized leaf coatings. Unlike dehydration tolerance, which involves surviving low internal water content, avoidance focuses on preventing the cellular potential from dropping.

30. (A) I, IV and V
Osmoprotectants like glycine betaine and proline are essential for cellular stability during stress. Glycine betaine is synthesized within chloroplasts, while proline is produced from glutamate in the cytosol. These molecules are highly compatible with cellular metabolism and do not perturb enzyme structures. Instead, they maintain hydration shells around proteins and membranes, protecting them from the damaging effects of dehydration and salinity.

31. (A) Cellular desiccation
Late embryogenesis abundant proteins are intrinsically disordered in their fully hydrated state, which allows them to remain highly flexible. However, as cellular desiccation occurs and water availability decreases, these proteins undergo a structural transition into alpha-helices. This folding process is essential for their function in stabilizing cellular membranes and preventing the aggregation of other proteins during the extreme cellular drying process.

32. (A) Hypoxia → Ethylene accumulation → Cell death/lysis → Aerenchyma formation
Waterlogging triggers a specific sequence of internal responses starting with hypoxia as oxygen levels drop. This condition leads to the rapid accumulation of ethylene in the roots, which acts as a signal for programmed cell death. The subsequent lysis of specific cortical cells results in the formation of aerenchyma, a specialized tissue that facilitates the diffusion of oxygen to roots.

33. (B) Rapid intracellular ice crystal formation
In non-acclimated plants, freezing injury is most commonly caused by the rapid formation of ice crystals within the cytoplasm. These intracellular crystals physically rupture the plasma membrane and internal organelles, leading to instantaneous and irreversible cellular death. Cold-acclimated plants avoid this by promoting ice formation in the extracellular spaces, which safely draws water out of the cell without causing physical damage.

34. (C) A is true but R is false.
Heat shock proteins act as molecular chaperones that facilitate the proper folding of nascent proteins and the refolding of those denatured by high temperatures. Their primary function is to maintain cellular proteostasis and prevent the toxic aggregation of damaged proteins. They do not typically function by degrading denatured proteins into individual amino acids, as that task is performed by different metabolic pathways.

35. (D) Photoinhibition of PSII
The D1 protein is a critical component of the photosystem II reaction center and is particularly susceptible to damage by excess light energy. Photoinhibition results in the inactivation of this protein, which must be rapidly turned over and replaced to restore photosynthetic activity. This specialized repair mechanism involves the degradation of the damaged D1 and the synthesis of a new functional subunit.

36. (B) II and III
Photoprotection involves several mechanisms to safeguard the plant from excess irradiance. Non-photochemical quenching is a process that safely dissipates surplus excitation energy as heat, preventing it from damaging the photosystems. Alternative electron sinks, such as the Mehler reaction and photorespiration, also play a role by preventing the over-reduction of the photosynthetic electron transport chain, which would otherwise lead to ROS formation.

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55. (A) Facilitating oxygen transport to submerged roots
Aerenchyma is a specialized tissue containing large gas-filled spaces that forms in the roots and stems of many plants during waterlogging. Its primary function is to facilitate the longitudinal transport of oxygen from the aerial parts of the plant to the submerged, oxygen-deprived roots. This anatomical adaptation allows for the maintenance of aerobic respiration and prevents the accumulation of toxic fermentation products.

56. (C) Leakage of cellular electrolytes
Exposure to cold temperatures causes cellular membranes to undergo a phase transition, leading to rigidification. This loss of fluidity impairs the function of membrane-bound proteins and increases the permeability of the lipid bilayer. Consequently, the cell experiences a significant leakage of electrolytes and other essential solutes. This disruption of ion homeostasis is a primary consequence of chilling injury and can lead to death.

57. (D) Membrane hyper-fluidity
The primary effect of heat stress on cellular membranes is the induction of hyper-fluidity. Elevated temperatures increase the kinetic energy of the lipid molecules, causing the bilayer to become excessively fluid and less stable. This structural change can lead to the detachment of peripheral proteins and the leakage of ions across the membrane. Plants often respond by increasing the saturation of fatty acids.

58. (C) PSII reaction center
The photosystem II reaction center is considered the most vulnerable site within the photosynthetic apparatus to damage from high light. This protein complex is particularly susceptible to photo-oxidation, which specifically targets the D1 subunit. Damage to this reaction center inhibits the electron transport chain and reduces overall efficiency. To mitigate this, plants have evolved complex repair mechanisms to rapidly replace damaged D1 proteins.

59. (B) Dissipating excess energy as heat
The xanthophyll cycle is a critical photoprotective mechanism that converts violaxanthin to zeaxanthin under high light intensities. This conversion is advantageous because zeaxanthin facilitates non-photochemical quenching, a process that dissipates excess excitation energy as harmless heat. By quenching surplus energy before it can reach the reaction centers, the xanthophyll cycle prevents the formation of reactive oxygen species and protects the machinery.

60. (D) A low Red to Far-Red ratio
Shade avoidance syndrome is primarily triggered by a reduction in the ratio of red to far-red light. As light passes through or reflects off the leaves of neighboring plants, red light is absorbed for photosynthesis while far-red light is transmitted. Phytochromes perceive this change in spectral quality as a signal of competition, inducing developmental adjustments, such as stem elongation, to help the plant compete for sunlight.

61. (A) It mirrors the response to pure water deficit.
The initial inhibition of growth during salinity stress is primarily due to the osmotic effect of salt in the soil. High concentrations of sodium and chloride ions lower the soil water potential, making it more difficult for roots to take up water. This physiological response closely mirrors the effects seen during pure water deficit, occurring rapidly before toxic ion levels accumulate.

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62. (C) Rapid vacuolar compartmentalization of sodium
Halophytes are specialized plants that can survive high salinity by efficiently managing internal ion concentrations. A key mechanism for their survival is the rapid compartmentalization of sodium ions into the large central vacuole. This process protects sensitive enzymes in the cytosol from sodium toxicity. Simultaneously, the accumulated vacuolar sodium acts as an osmoticum to help the plant maintain turgor and extract water.

63. (A) Lateral root and apex inhibition
Aluminum toxicity is a major growth-limiting factor in acidic soils, primarily manifesting as the inhibition of root development. Toxic aluminum ions specifically target the root apex and lateral root initials, disrupting cell division and expansion. This damage results in a stunted and poorly branched root system, which severely compromises the plant's ability to acquire water and nutrients, leading to growth reductions.

tocopherol or Vitamin E, are crucial for protecting the plasma membrane and other lipid bilayers from oxidative damage. They function by intercepting lipid peroxyl radicals and terminating the chain reaction of lipid peroxidation, thereby preserving the structural integrity and fluidity of cellular membranes during periods of stress.

47. (C) I, II and V
Abiotic stress concepts are often defined by their physiological impacts. Eustress refers to mild, potentially beneficial stress that does not lead to cell death. Elastic deformation signifies a reversible response rather than a permanent loss. Furthermore, stress strictly refers to adverse environmental conditions that deviate from the optimum. Strain is the biological consequence of these stressors, and plastic deformation occurs when limits are exceeded.

48. (D) Water potential
Water potential is the comprehensive term used to define the total chemical potential of water in a plant cell relative to pure water. It determines the direction of water movement, as water always flows from regions of higher potential to lower potential. This value is influenced by several components, including solute concentration and physical pressure, and is measured in units of pressure.

49. (D) Transpiration
Transpiration is the most significant mechanism used by plants to dissipate excess sensible heat and maintain a stable leaf temperature. As water evaporates from the leaf surfaces, it consumes a large amount of energy known as the latent heat of vaporization. This process provides an efficient cooling effect that prevents thermal damage to sensitive cellular components and enzymes, even under high radiation.

50. (B) Guard cells lose turgor, leading to stomatal closure.
When plants are exposed to elevated vapor pressure deficit, the rate of water loss from the leaves can exceed the rate of uptake. This imbalance causes guard cells to lose turgor pressure, leading to the closure of stomatal pores. This hydraulic response is a critical survival mechanism that helps minimize further transpiration and prevents severe tissue dehydration, although it also restricts carbon dioxide entry.

51. (B) Harvest index is irrelevant to final yield.
Passioura's yield model is a fundamental framework in crop physiology that expresses grain yield as the product of total water transpired, water use efficiency, and the harvest index. Contrary to incorrect assumptions, the harvest index is highly relevant as it represents the efficiency with which a plant partitions its accumulated biomass into economically valuable harvested organs. All three components are essential.

52. (A) Dehydration tolerance – LEA accumulation
Drought adaptation involves various strategies such as escape, avoidance, and tolerance. Dehydration tolerance specifically refers to the ability of plant tissues to survive low internal water potentials, often facilitated by the accumulation of protective late embryogenesis abundant proteins. Drought escape is characterized by phenological adjustments like rapid life cycles, while avoidance mechanisms focus on maintaining hydration through deep roots.

53. (B) Mannitol – Lipid
Osmoprotectants are small, non-toxic molecules that help plants cope with osmotic stress. Proline is an amino acid, glycine betaine is a quaternary ammonium compound, and trehalose is a disaccharide. Mannitol is a sugar alcohol rather than a lipid. These molecules accumulate in the cytosol to lower the osmotic potential and protect cellular structures from denaturation without interfering with normal metabolic pathways.

54. (B) They possess intense enzymatic hydrolytic activity.
Dehydrins are a specific sub-family of late embryogenesis abundant proteins that lack a defined three-dimensional structure in solution. They are characterized by highly conserved sequences known as K-segments, which are thought to stabilize membranes and other proteins. Unlike enzymes, dehydrins do not possess hydrolytic or catalytic activity. Instead, they function as molecular shields or chaperones that provide protection against dehydration.

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73. (A) Modifying guard cell turgor via passive hydraulic feedback.
High vapor pressure deficit creates a steep gradient between the leaf interior and the atmosphere, increasing evaporation. This high demand for water can outpace the supply to the guard cells, leading to a loss of turgor pressure through passive hydraulic feedback. As guard cells lose their turgidity, they physically collapse and close the stomatal pore, helping the plant conserve water and maintain hydration.

74. (D) Maximizing early soil water capture.
According to physiological models, crops can maximize yield under drought by effectively capturing soil water early in the growing season. This strategy ensures that the plant has sufficient moisture for establishment and vegetative growth before the onset of terminal drought. By maximizing water uptake and maintaining a high harvest index, the plant can translate available resources into grain production more efficiently than other strategies.

75. (A) A phenological adjustment
Drought escape is fundamentally categorized as a phenological adjustment rather than a biochemical or cellular defense. It involves the modification of the plant's life cycle to ensure that the most sensitive reproductive stages occur during periods of favorable moisture. By rapidly completing their development before soil water is depleted, plants can successfully produce seeds and survive without enduring physiological dehydration and stress.

76. (A) Protect the oxygen-evolving complex of PSII.
Glycine betaine is a potent osmoprotectant that accumulates in certain species during stress. Its primary function is to stabilize cellular structures and proteins, particularly the oxygen-evolving complex of photosystem II. By protecting these sensitive components from denaturation, glycine betaine helps maintain photosynthetic efficiency. It also aids in osmotic adjustment, helping the cell maintain turgor and continue metabolic functions even at high salinity.

77. (A) Fundamental biological desiccation mechanism
The widespread presence of late embryogenesis abundant proteins across diverse kingdoms, including plants, nematodes, and bacteria, suggests they are part of a fundamental biological mechanism for desiccation tolerance. These proteins are specifically evolved to protect cellular integrity during extreme water loss. Their conserved nature indicates that the physical challenges of dehydration are universal, and these proteins provide a common evolutionary solution.

78. (B) Minimal ATP required for brief survival.
In waterlogged roots, the absence of oxygen prevents aerobic respiration, forcing the plant to rely on fermentative metabolism. While fermentation is much less efficient than oxidative phosphorylation, it ensures the continued production of minimal amounts of ATP necessary for brief survival. This process allows root cells to maintain basic maintenance functions and ion gradients until oxygen levels improve or the plant forms adaptations.

79. (A) Prevention of membrane transition to a gel phase
Accumulating unsaturated fatty acids in cellular membranes is a key adaptation during cold acclimation. Unsaturated lipids have lower melting points and introduce kinks into the fatty acid chains, which prevents the membrane from transitioning into a rigid gel phase at low temperatures. By maintaining the liquid-crystalline state, the membrane remains fluid and functional, allowing for continued activity of essential transport proteins.

80. (D) Thermotolerance
Thermotolerance is the term used to define the acquired ability of a plant to survive otherwise lethal high temperatures. This is typically achieved through a pretreatment with mild heat, which triggers the synthesis of heat shock proteins and other protective molecules. This acclimation process prepares the cellular machinery for more severe stress by stabilizing proteins, thereby increasing the plant's overall resilience and capacity.

81. (A) Pigment bleaching and lipid peroxidation
Extensive photo-oxidation in chloroplasts is a destructive process that occurs when light energy exceeds the plant's capacity for safe dissipation. The resulting reactive oxygen species cause the bleaching of photosynthetic pigments and the peroxidation of thylakoid membrane lipids. This leads to the breakdown of the photosynthetic

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needed for glycolysis but produces significantly less ATP than oxidative phosphorylation.

10. (A) Membrane phase transition → ROS production → Ion leakage → Necrosis
Chilling injury in sensitive plants follows a specific sequence of physiological events starting with a membrane phase transition from liquid-crystalline to solid-gel. This structural change impairs membrane-bound enzymes and leads to the excessive production of reactive oxygen species. Consequently, membrane integrity is compromised, causing electrolyte and ion leakage from the cells, which eventually results in visible tissue death.

11. (B) Increased saturation of fatty acids
Maintaining membrane stability during heat stress requires an increase in the proportion of saturated fatty acids in the lipid bilayer. Saturated lipids have higher melting points and provide greater structural rigidity, which counteracts the excessive fluidization caused by elevated temperatures. This modification prevents the breakdown of membrane integrity and ensures the continued functioning of embedded proteins and essential transport systems.

12. (C) II and IV
High light stress leads to several detrimental effects, including the degradation of the D1 protein within the photosystem II reaction center and the production of superoxide via the Mehler reaction. Photo-oxidation can also cause the bleaching of photosynthetic pigments. Incorrect assumptions include the idea that photoinhibition only damages photosystem I or that high light conditions strictly reduce reactive species generation.

13. (A) Zeaxanthin
During peak non-photochemical quenching, the xanthophyll cycle is activated to protect the photosynthetic apparatus from excess light energy. The pigment zeaxanthin accumulates maximally through the de-epoxidation of violaxanthin under high-light conditions. Zeaxanthin facilitates the safe dissipation of excess excitation energy as heat, thereby preventing the formation of reactive oxygen species and damage to the photosystem II reaction centers.

14. (A) I, II, III, IV
Shade avoidance syndrome signaling begins with the perception of a low red to far-red light ratio by phytochromes. This trigger causes phytochromes to shift into the inactive Pr form, which leads to the stabilization of phytochrome interacting factors in the nucleus. These transcription factors then activate the expression of genes responsible for morphological changes, such as rapid stem elongation.

15. (A) The osmotic phase of salt stress
The immediate reduction in shoot growth following salt exposure is primarily attributed to the osmotic phase of stress. High salt concentrations in the soil solution lower the external water potential, making it difficult for roots to extract water. This effectively induces a physiological drought, leading to a rapid decline in cell expansion and stomatal conductance before significant ion toxicity occurs.

16. (A) P-2, Q-3, R-1, S-4
The salt overly sensitive pathway coordinates the plant's response to sodium toxicity through specific protein components. SOS3 acts as a calcium sensor that detects stress-induced signals, while SOS2 is a protein kinase that relays the message. SOS1 is a plasma membrane antiporter that extrudes sodium from the cytoplasm, and NHX1 is a vacuolar antiporter that sequesters sodium into vacuoles.

17. (B) Root apical meristem division and activity
Aluminum toxicity in acidic soils is characterized by the rapid inhibition of root growth, specifically targeting the root apical meristem. Upon exposure, aluminum ions interfere with cell division and expansion in the transition zone of the root tip. This immediate disruption of meristematic activity leads to stunted, thickened roots, which severely limits the plant's ability to acquire water and nutrients.

18. (A) Both A and R are true and R is the correct explanation of A.
Phytochelatins are cysteine-rich peptides that are enzymatically synthesized from glutathione in response to heavy metal exposure. These peptides serve a critical detoxification role by forming direct stable complexes with toxic metal ions in the cytosol. Once formed, these complexes are actively transported and sequestered into the central vacuole, preventing the metals from

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91. (B) Hydroxyl radicals via the Haber-Weiss reaction
The simultaneous activity of superoxide dismutase and catalase is essential for preventing the formation of more dangerous reactive species. Superoxide dismutase converts superoxide into hydrogen peroxide, which catalase then breaks down into water and oxygen. By efficiently removing these precursors, the enzymes prevent the occurrence of the Haber-Weiss reaction, which would otherwise generate the highly toxic and destructive hydroxyl radical.

92. (A) It requires continuous stoichiometric regeneration of reductants.
A major disadvantage of the non-enzymatic reactive species scavenging system is that it requires the continuous and stoichiometric regeneration of reductants like ascorbate and glutathione. Unlike enzymes, which can catalyze multiple reactions without being consumed, non-enzymatic antioxidants are directly oxidized during the process. To remain functional, they must be converted back to their reduced forms through energy-dependent pathways, creating high metabolic demand.

93. (C) Elastic limit
The elastic limit is the specific point in plant mechanics where tissue deformation under stress becomes permanent. Below this limit, any structural changes are reversible, and the tissue can return to its original state once the stress is removed. However, once the elastic limit is exceeded, the plant undergoes plastic strain, which involves irreversible damage. Identifying this threshold is crucial for understanding.

94. (A) Psi = Solute Potential + Pressure Potential
In mature, vacuolated plant cells, water potential is primarily governed by the combination of solute potential and pressure potential. Solute potential represents the effect of dissolved substances on water's free energy, and it is always negative. Pressure potential, or turgor pressure, is the physical force against the cell wall and is typically positive. These components are the dominant factors determining water movement.
Ψ = Solute Potential + Pressure Potential

95. (A) Smaller leaves have thinner boundary layers and higher sensible heat loss.
Canopy energy balance is significantly influenced by leaf morphology and environmental conditions. Smaller leaves are characterized by thinner boundary layers of still air, which facilitates more efficient gas exchange and heat transfer. This leads to a higher rate of sensible heat loss to the surrounding atmosphere, helping the plant maintain a lower leaf temperature. In contrast, larger leaves have thicker boundary layers.

96. (D) ABA promotes the opening of inward-rectifying potassium channels.
Guard cell mechanics involve precise movements of ions and water to regulate stomatal aperture. Stomatal opening is driven by ATP-powered proton efflux and subsequent influx of potassium. Elevated cytosolic calcium is a known signal that triggers closure. However, an incorrect description suggests that ABA promotes the opening of inward-rectifying potassium channels. In reality, ABA inhibits these channels while activating outward-rectifying ones.

97. (A) Passioura's Model – Yield = Water Transpired × WUE × Harvest Index
Passioura's yield model is a widely recognized framework in agricultural research that quantifies grain yield as a product of three key factors: the total amount of water transpired, the water use efficiency, and the harvest index. This model helps researchers identify specific physiological traits that can be targeted for improvement in breeding programs. Correct understanding emphasizes that all three components are essential.
Yield = Water Transpired × WUE × Harvest Index

98. (B) Phreatophytes – Drought escape
Drought adaptation strategies are categorized based on how plants survive water shortages. Resurrection plants exhibit extreme dehydration tolerance, while desert ephemerals use drought escape. Succulents avoid dehydration by storing water in specialized tissues. However, phreatophytes are deep-rooted plants that access permanent groundwater, making them examples of dehydration avoidance rather than drought escape. They maintain hydration by ensuring a steady water supply.

99. (D) Hydrogen peroxide
Compatible solutes are small, non-toxic molecules that accumulate in cells to lower osmotic potential and protect structures during stress. Common examples include amino acids like proline and

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disaccharides like trehalose. These molecules do not interfere with cellular metabolism even at high concentrations. Hydrogen peroxide is a reactive oxygen species rather than a compatible solute. Its accumulation is generally harmful and managed by antioxidants.

100. (A) Proteins accumulating during seed desiccation
Late embryogenesis abundant proteins are a group of highly hydrophilic, intrinsically disordered proteins that were first identified in maturing plant seeds. They accumulate in massive quantities during the final stages of seed development as the embryo undergoes natural desiccation. Their primary function is to protect cellular membranes and other proteins from the damaging effects of water loss, ensuring that the seed remains viable.

101. (B) 2 ATP
During anoxia or a total lack of oxygen, aerobic respiration is completely inhibited because the electron transport chain lacks its final acceptor. As a result, the plant must shift to fermentative metabolism to generate energy. This pathway restricts the cellular ATP yield to only two molecules per glucose molecule, which are produced during glycolysis. This is significantly less than generated during aerobic respiration.

102. (B) Tropical and subtropical zones
Chilling injury primarily affects plants that originate from tropical and subtropical regions, where temperatures rarely drop below 10 to 15 degrees Celsius. These species lack the adaptive mechanisms necessary to maintain membrane fluidity and metabolic balance at low temperatures. When exposed to chilling, they experience rapid physiological dysfunction, including membrane rigidification and ion leakage. In contrast, alpine plants have evolved specific acclimation processes.

103. (A) It is actively preventing protein aggregation.
When a plant heavily upregulates the expression of heat shock protein 70 during heat stress, it can be inferred that it is actively working to prevent the aggregation of denatured proteins. HSP70 acts as a molecular chaperone that binds to misfolded proteins, helping them return to functional shapes. This activity is crucial for maintaining cellular proteostasis and preventing toxic protein aggregate buildup.

104. (C) The D1 protein of the PSII reaction center
The primary mechanism of photoinhibition involves specific damage to the photosystem II reaction center, particularly the D1 protein subunit. This protein is essential for the transfer of electrons within the photosystem but is highly sensitive to the reactive species generated during excess light absorption. When damaged, the D1 protein must be replaced by the cell's repair machinery to restore photosynthetic function.

105. (D) Quenching chlorophyll triplets and singlet oxygen.
The xanthophyll cycle is a vital photoprotective mechanism that provides a major advantage during periods of excess irradiance. By converting violaxanthin to zeaxanthin, the plant can more effectively quench chlorophyll triplet states and prevent the formation of highly reactive singlet oxygen. This process safeguards the photosynthetic apparatus from photo-oxidative damage by dissipating excess excitation energy as harmless heat within the chloroplast.

106. (C) Shade Avoidance Syndrome
Shade avoidance syndrome is the specific term used to classify the morphological adaptations that occur when plants perceive a low red to far-red light ratio, signaling nearby competitors. Characteristic responses include rapid stem elongation, reduced leaf area, and accelerated flowering. These changes are part of a developmental strategy to position leaves in higher, more favorable light conditions within a dense canopy.

107. (B) Reduced water potential of the soil solution.
The immediate trigger for the osmotic phase of salinity stress is the reduction in the water potential of the soil solution caused by high concentrations of dissolved salts. This change decreases the potential gradient between the soil and roots, making it more difficult to extract water. This effect occurs instantaneously and induces a state of physiological drought, leading to rapid reductions in expansion.

108. (D) Sodium is sequestered into the vacuole to lower cytosolic toxicity.
Ion compartmentalization is a critical strategy for managing salt stress in many plants. By actively sequestering sodium ions into the large central vacuole, the cell can keep the concentration of toxic ions in the cytoplasm at low levels.

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This protects sensitive cytosolic enzymes from damage. Furthermore, accumulated sodium in the vacuole contributes to osmotic potential, helping the plant maintain turgor pressure necessary for growth.

109. (A) Aluminum toxicity is most severe in highly acidic soils (pH < 5.0).
While aluminum toxicity is widely associated with acidic soils, identifying it as exclusively or most severe only below pH 5.0 can be technically incorrect as toxicity thresholds vary between species and soil types. Aluminum becomes increasingly soluble at low pH, but its biological impact depends on the specific forms present and the plant's inherent sensitivity or various internal resistance and exclusion mechanisms.
Aluminum toxicity is most severe in highly acidic soils ($pH < 5.0$).

110. (B) Metallothioneins – Gene-encoded peptides
Heavy metal detoxification involves two main classes of metal-binding ligands. Metallothioneins are low-molecular-weight peptides that are directly encoded by genes and synthesized on ribosomes. In contrast, phytochelatins are synthesized enzymatically from glutathione. These gene-encoded metallothioneins play a vital role in maintaining metal homeostasis and providing tolerance by chelating toxic ions through their high cysteine content, effectively preventing cellular damage.

111. (A) PP2C – Negative regulator of ABA signaling
In the abscisic acid signaling pathway, several components work together to relay the stress signal. PYR/PYL proteins act as soluble receptors, and SnRK2s are protein kinases that serve as positive regulators. However, type 2C protein phosphatases such as PP2C are actually negative regulators of the pathway. They function by dephosphorylating and inactivating SnRK2 kinases in the absence of the hormone.

112. (D) Immediate induction of rapid leaf abscission
Cytokinins play several important roles in helping plants cope with environmental stress, including the maintenance of source-sink relationships and the delay of leaf senescence. They may also contribute to the scavenging of some reactive oxygen species. Unlike stress-induced hormones such as abscisic acid, cytokinins do not typically induce rapid leaf abscission. Instead, they work to preserve the lifespan of tissues.

113. (A) Imbalance where ROS exceeds scavenging
Oxidative stress is defined as a physiological state where the production of reactive oxygen species exceeds the plant's capacity to neutralize them through its antioxidant defense systems. This imbalance leads to the accumulation of toxic reactive species that can cause indiscriminate damage to essential cellular components, including lipids and DNA. Maintaining a balance is critical for survival and proper signaling pathway function.

114. (B) Hydrogen peroxide and Oxygen
Superoxide dismutase is a primary example of an antioxidant enzyme that provides the first line of defense against oxidative damage. It catalyzes the dismutation of the superoxide anion, a byproduct of various metabolic processes, into hydrogen peroxide and molecular oxygen. While hydrogen peroxide is still a reactive species, it is less destructive than superoxide and can be further neutralized by enzymes like catalase.

115. (A) Ascorbate
The Foyer-Halliwell-Asada cycle is a central pathway for the detoxification of hydrogen peroxide in plant cells, especially within chloroplasts. This cycle fundamentally relies on the continuous oxidation and reduction of ascorbate, which serves as a major non-enzymatic antioxidant and electron donor. By cycling between its reduced and oxidized forms, ascorbate facilitates the conversion of harmful peroxide into water and oxygen.

116. (B) Strain
In the context of abiotic stress, strain refers to the internal biological changes or consequences that occur in a plant as a result of an applied environmental stressor. While the stress is the external force or condition, the strain represents the plant's actual response, which can be either elastic and reversible or plastic and permanent. Understanding the relationship is essential for characterization.

117. (A) Pressure potential is zero; Water potential equals Solute potential.
Incipient plasmolysis is the point at which the protoplast just begins to pull away from the cell wall due to water loss. At this specific stage, the pressure potential or turgor pressure within the cell drops to exactly zero. Consequently, the total water potential of the cell becomes equal

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136. (A) Its lack of any specific enzymatic scavenger).
The hydroxyl radical is the most reactive and destructive species among all reactive oxygen species. Its extreme toxicity is primarily due to the fact that there is no known specific enzymatic scavenger that can neutralize it. Because it reacts indiscriminately and almost instantaneously with any nearby biological molecule, it causes severe damage to proteins, lipids, and DNA at its generation site.

137. (A) Dismutation
Catalase is a highly efficient enzyme that facilitates the conversion of hydrogen peroxide into water and molecular oxygen. This specific enzymatic process is often referred to as dismutation or disproportionation, as the enzyme acts on two molecules of the same substrate to produce different products. Catalase is primarily found in peroxisomes, where it prevents the accumulation of toxic peroxide levels.

138. (A) Alpha-tocopherol
Alpha-tocopherol, also known as Vitamin E, is the primary lipid-soluble antioxidant found within the thylakoid membranes of chloroplasts. It plays a critical role in protecting these membranes from lipid peroxidation by intercepting and neutralizing lipid peroxyl radicals. By terminating the chain reaction of oxidation, alpha-tocopherol preserves the structural integrity and function of the thylakoid bilayer, which is essential for photosynthesis.

139. (A) It results in irreversible structural changes or damage.
In plant mechanics, plastic deformation is a term used to describe structural changes that are irreversible. This occurs when an environmental stressor is severe enough to push the tissue beyond its elastic limit, leading to permanent damage or alteration of the cell walls and other components. Unlike elastic strain, which allows for recovery, plastic deformation represents a lasting change in plant form.

140. (D) Matric potential is the dominant component in fully hydrated mature leaves.
Cellular water potential is determined by several components, but their relative importance varies with the plant's status. In fully hydrated mature leaves, the dominant components are solute potential and pressure potential, while matric potential is generally negligible. A common misconception is that matric potential is dominant in these tissues; in reality, it only becomes a major factor in very dry seeds.

141. (A) Latent heat flux – Energy used for transpiration
In the study of plant canopies, energy balance components are used to describe how plants manage solar radiation. Latent heat flux is correctly defined as the energy consumed during the evaporation of water from leaf surfaces during transpiration. This process is a major cooling mechanism. In contrast, sensible heat flux involves heat transfer to the air, and net radiation represents total balance.

142. (C) Stomatal opening – ABA synthesis
Stomatal mechanics involve the precise regulation of turgor in guard cells to control the pore size. Stomatal opening is driven by potassium influx and the synthesis of malate, which lower the solute potential and draw water in. Stomatal closure is triggered by high vapor pressure deficit or abscisic acid. An incorrect pairing suggests that ABA synthesis leads to opening; however.

143. (D) Maximized cuticular transpiration
Water use efficiency is a measure of how effectively a plant uses available water for biomass production. WUE can be physiologically increased through mechanisms such as partial stomatal closure, which reduces water loss, or by having small leaves to decrease boundary layer resistance. Maximizing cuticular transpiration, however, would be detrimental as it involves uncontrolled water loss through the leaf surface, thereby decreasing efficiency.

144. (A) Active net accumulation of solutes to lower osmotic potential.
Osmotic adjustment is a physiological process where plants actively accumulate solutes, such as compatible osmoprotectants or inorganic ions, within their cells. This net accumulation lowers the cellular osmotic potential, which allows the plant to maintain a favorable water potential gradient and continue absorbing water from dry soils. By sustaining turgor pressure, osmotic adjustment enables the plant to continue growth and development.

145. (A) They do not disrupt enzymes at high levels.
The accumulation of compatible solutes, also known as osmoprotectants, provides a significant

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mechanism is a key component of both basal and acquired thermotolerance.

127. (A) Photoinhibition
Photoinhibition is the term used to describe the light-induced reduction in photosynthetic capacity that occurs when the absorption of light energy exceeds the plant's ability to utilize it for carbon fixation. This process primarily involves damage to the photosystem II reaction centers, specifically the D1 protein subunit. While plants have repair mechanisms, prolonged excess light can lead to permanent damage and photo-oxidation.

128. (D) Thylakoid membrane
The enzymes of the xanthophyll cycle, such as violaxanthin de-epoxidase and zeaxanthin epoxidase, are located within the thylakoid membranes of the chloroplast. This specific localization ensures that photoprotective pigments are positioned exactly where they are needed to dissipate excess excitation energy from the light-harvesting complexes. The activity of these enzymes is regulated by the pH of the thylakoid lumen.

129. (A) Far-Red light converts the active Pfr form back to the inactive Pr form.
Phytochromes exist in two interconvertible forms that allow plants to monitor light quality. The active Pfr form is produced by red light, while far-red light converts it back to the inactive Pr form. Under a plant canopy, much red light is absorbed by upper leaves, resulting in a shade environment rich in far-red light. This shift toward the Pr form.

130. (D) The ionic phase strictly precedes the osmotic phase.
Salinity stress involves two distinct phases with different physiological impacts. The osmotic phase occurs immediately upon salt exposure and is characterized by a rapid reduction in growth due to lowered potential. The ionic phase develops more slowly as toxic ions accumulate. Incorrect assumptions include the idea that the ionic phase precedes the osmotic phase. In reality, immediate growth reduction is osmotic.

131. (A) SOS3 – Calcium sensor
The salt overly sensitive pathway is a critical signaling cascade for managing sodium toxicity. SOS3 is a specialized calcium-binding protein that acts as a sensor for stress-induced calcium signals. Upon binding calcium, SOS3 interacts with and activates the SOS2 protein kinase. This complex then phosphorylates and activates the SOS1 Na^+/H^+ antiporter at the plasma membrane, which extrudes sodium from the cell.

132. (B) Lead – Highly mobile in phloem
Heavy metal toxicity involves various elements with distinct behaviors and effects. Aluminum primarily inhibits root apex growth in acidic soils, while arsenic acts as a phosphate mimic, disrupting energy metabolism. Cadmium is known to induce severe oxidative stress. However, lead is characterized by its very low mobility within the plant's phloem. Once absorbed by roots, most lead remains sequestered.

133. (D) Phytochrome interacting factors (PIFs)
The detoxification of heavy metals involves several specialized components. Glutathione acts as a precursor, and the enzyme phytochelatin synthase produces metal-binding peptides. ABC transporters are then responsible for sequestering these complexes. PIFs, however, are transcription factors involved in light signaling and photomorphogenesis rather than heavy metal detoxification. Their primary role is to regulate plant development in response to light quality and shade.

134. (A) Soluble ABA receptors that inhibit PP2Cs
The PYR/PYL/RCAR protein complex consists of soluble receptors for abscisic acid that play a central role in the hormone's signaling pathway. When ABA binds to these receptors, they undergo a conformational change that allows them to interact with and inhibit type 2C protein phosphatases. This inhibition is the key step that allows for the activation of SnRK2 kinases for stress responses.

135. (A) Chlorophyll biosynthesis and photosynthetic genes
Cytokinins are known to counteract stress-induced leaf senescence by maintaining the metabolic activity of the tissue. They achieve this by promoting the expression of genes involved in chlorophyll biosynthesis and photosynthesis, which helps sustain the leaf's carbon-fixing capacity. By preventing the breakdown of the photosynthetic apparatus, cytokinins delay the remobilization of nutrients and extend the functional lifespan of the stressed leaf.

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only two ATP molecules per glucose molecule. Aerenchyma tissue is an important facilitating anatomical adaptation.

172. (D) Enhanced efficiency of the photosynthetic electron transport chain
Chilling injury in susceptible plants involves several detrimental physiological changes, including the phase transition of membranes from a liquid-crystalline to a solid-gel state. This structural shift leads to increased electrolyte leakage and the accumulation of reactive oxygen species. Contrary to incorrect claims, chilling stress does not enhance the efficiency of the photosynthetic electron transport chain. Instead, it significantly impairs photosynthesis by damaging reaction.

173. (A) Increased kinetic energy destabilizing lipid-lipid and lipid-protein interactions.
The structural reason for heat-induced membrane hyper-fluidity is the increased kinetic energy of the lipid molecules at high temperatures. This surplus energy destabilizes the non-covalent lipid-lipid and lipid-protein interactions that maintain the membrane's structural integrity. As a result, the bilayer becomes excessively fluid and more permeable, which can lead to the leakage of ions and the dysfunction of enzymes.

174. (B) FtsH protease
During photoinhibition, the D1 protein of the photosystem II reaction center is specifically damaged by reactive species and must be replaced. This degradation is a critical step in the PSII repair cycle and is primarily executed by specific proteases, most notably the FtsH protease. This enzyme recognizes the damaged D1 subunit and facilitates its removal from the thylakoid membrane, restoring activity.

175. (D) Zeaxanthin
During prolonged high light stress, the xanthophyll cycle is activated as a photoprotective mechanism to dissipate excess energy. This process involves the sequential de-epoxidation of violaxanthin to zeaxanthin via the intermediate antheraxanthin. Under these conditions, the steady-state level of zeaxanthin increases dramatically within the thylakoid membranes. Zeaxanthin facilitates non-photochemical quenching, which safely converts surplus light energy into dissipated heat.

176. (A) Photomorphogenesis
Photomorphogenesis is the term used to describe the phytochrome-mediated developmental changes that occur when a seedling emerges from the soil and is first exposed to light. This process ensures survival by triggering the transition from skotomorphogenesis to a state of light-regulated growth. In response to red light, phytochromes activate genes that promote leaf expansion, chlorophyll synthesis, and development of photosynthetic apparatus.

177. (A) Physiological drought due to lowered soil water potential
The immediate primary effect of soil salinity on non-halophytic plants is the induction of physiological drought. High concentrations of salts in the soil solution lower its water potential, making it more difficult for the roots to extract moisture. This effect occurs almost instantaneously and results in a rapid reduction in turgor pressure and growth before any toxic ions have accumulated in tissues.

178. (A) It utilizes the proton gradient established by the plasma membrane H^+-ATPase to extrude sodium.
SOS1 is a plasma membrane Na^+/H^+ antiporter that plays a critical role in salt tolerance by extruding toxic sodium from the cytoplasm into the apoplast. Its activity is driven by the proton gradient created by the plasma membrane H^+-ATPase, which provides necessary energy for the secondary active transport of sodium. By efficiently removing sodium, SOS1 helps maintain low cytosolic ion concentrations.

179. (D) Aluminum strictly enhances phosphorus availability.
Aluminum toxicity is a significant problem in acidic soils where pH is below 5.0, as it becomes more soluble and inhibits root elongation. Plants often achieve tolerance by exuding organic acids from their roots to chelate aluminum ions. A common misconception is that aluminum enhances phosphorus availability; in reality, aluminum ions react with phosphate to form insoluble complexes, reducing phosphorus availability.

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180. (A) Citrate/Malate exudation – Aluminum exclusion mechanism
In many plants, aluminum tolerance is achieved through an exclusion mechanism involving the

advantage over the use of inorganic ions for osmotic adjustment. Unlike simple ions, these molecules are highly compatible with cellular metabolism and do not disrupt enzyme function even at high concentrations. This allows the plant to lower its osmotic potential and maintain turgor without interfering with essential biochemical processes.

146. (A) Highly conserved K-segments
Dehydrins are a specific sub-family of late embryogenesis abundant proteins characterized by the presence of highly conserved structural motifs known as K-segments. These lysine-rich sequences are thought to form amphipathic alpha-helices that can interact with and stabilize cellular membranes and other proteins during periods of desiccation. This structural feature is essential for their role as molecular chaperones, providing protection against water loss.

147. (A) Lysigeny
Lysigeny is the term used to describe the programmed cell death process that leads to the formation of aerenchyma tissue in plants, particularly under waterlogged conditions. This process involves the deliberate breakdown and lysis of specific cortical cells, creating large gas-filled cavities within the roots. These spaces facilitate the internal transport of oxygen from the aerial parts to the submerged, oxygen-deprived root tissues.

148. (A) Synthesizing antifreeze proteins and promoting extracellular ice nucleation
Plants have evolved sophisticated mechanisms to prevent lethal intracellular freezing during cold stress. This is achieved by synthesizing antifreeze proteins and by promoting ice nucleation in the extracellular spaces. By ensuring that ice forms only outside the cell, the plant causes a controlled withdrawal of water from the cytoplasm. This regulated process allows the plant to survive freezing temperatures without experiencing cellular physical rupture.

149. (A) They introduce double bonds into fatty acids to maintain fluidity.
Membrane lipid desaturases are essential enzymes that play a critical role during cold acclimation. They function by introducing double bonds into the fatty acid chains of membrane lipids, which increases the proportion of unsaturated fatty acids. These double bonds create kinks in the lipid molecules, preventing them from packing tightly together. By maintaining membrane fluidity, these enzymes ensure the continued functioning of proteins.

150. (D) They are synthesized exclusively during heat stress.
Heat shock proteins are a group of molecular chaperones that facilitate proper protein folding and prevent aggregation during thermal stress. Their expression is regulated by heat shock factors. A common misconception is that they are synthesized exclusively during heat stress; in reality, many HSPs are constitutively expressed at low levels or can be induced by other stressors such as drought or cold.

151. (A) PSII – Primary site of D1 damage
Within the chloroplast, the photosystem II reaction center is recognized as the primary site of damage during high light stress. Specifically, the D1 protein subunit within PSII is highly susceptible to photo-oxidation and must be rapidly degraded and replaced to restore photosynthetic function. While other components like PSI play vital roles, the cycle of D1 damage and repair is a central feature.

152. (D) Xanthophyll cycle – Operates strictly in the dark.
Photoprotection involves mechanisms to dissipate excess light energy, such as non-photochemical quenching and the xanthophyll cycle. Violaxanthin de-epoxidase is an enzyme activated by low lumen pH, signaling the accumulation of surplus energy. An incorrect pairing suggests that the xanthophyll cycle operates strictly in the dark; in reality, it is a light-dependent process that is rapidly activated by high light to protect tissues.

153. (C) Increased leaf thickness
Shade avoidance syndrome is characterized by classic morphological and developmental responses to low light quality. These include stem elongation, upward leaf movement known as hyponasty, and accelerated flowering. Contrary to incorrect claims, shade-avoiding plants typically exhibit a decrease in leaf thickness and an increase in specific leaf area. This allows the plant to maximize surface area available for capture with minimal investment.

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154. (A) It is driven by the gradual, toxic accumulation of Na^+ and Cl^-.
The second, ionic phase of salt stress is a more gradual process compared to the immediate osmotic phase. It is driven by the toxic accumulation of sodium and chloride ions within the plant's tissues over time. As these ions reach inhibitory levels, they interfere with essential cellular processes, leading to specific tissue damage. This phase is particularly detrimental as it impacts metabolic capacity.

155. (A) Transporting sodium from the cytosol into the vacuole
The NHX1 antiporter is a critical component of the plant's salt tolerance mechanism, located on the tonoplast. Its function is to transport sodium ions from the cytosol into the large central vacuole, utilizing the proton gradient established by vacuolar H^+-ATPases. This sequestration reduces the concentration of toxic sodium in the cytoplasm, protecting sensitive enzymes. Simultaneously, the accumulated sodium helps maintain cellular turgor.

156. (A) Limiting water and nutrient uptake
Aluminum-induced damage to the root apex is a major factor restricting overall plant growth in acidic soils. By inhibiting cell division in the root tip, aluminum results in a stunted root system. This structural impairment severely limits the plant's capacity for water and nutrient uptake from the soil. Consequently, the plant experiences physiological drought and nutrient deficiencies, leading to a decline.

157. (B) Vacuole
The vacuole serves as the final storage compartment for heavy metal-phytochelatin complexes during the detoxification process. Once toxic metals are chelated by phytochelatins in the cytosol, the resulting complexes are actively transported across the tonoplast and into the central vacuole. This sequestration effectively isolates the toxic ions from the sensitive metabolic pathways of the cytoplasm. Safe storage allows plants to tolerate metals.

158. (A) Receptor binds and inhibits a PP2C
The immediate biochemical consequence of abscisic acid binding to its PYR/PYL receptors is the formation of a complex that can interact with type 2C protein phosphatases. The receptor binds to the active site of the PP2C, effectively inhibiting its phosphatase activity. This is the crucial first step in the signaling pathway, as it prevents the PP2C from dephosphorylating and inactivating SnRK2.

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159. (B) Cytokinin generally antagonizes ABA-induced stress responses.
Abscisic acid and cytokinins often play antagonistic roles in plant responses to abiotic stress. While ABA acts as a primary stress hormone that promotes stomatal closure and the onset of senescence to conserve resources, cytokinins generally function to delay senescence and maintain growth. Under stress conditions, the reduction in cytokinin levels often facilitates the action of ABA in various physiological processes.

160. (D) Singlet oxygen is primarily generated during normal mitochondrial respiration.
Reactive oxygen species are generated as byproducts of various metabolic pathways and serve as important signaling molecules. A common misconception is that singlet oxygen is primarily generated during mitochondrial respiration; in fact, it is mostly produced in the chloroplasts during photosynthesis, particularly under high light conditions where triplet state chlorophyll reacts with ground-state oxygen. Mitochondrial respiration typically produces superoxide and peroxide.

161. (A) SOD – Requires metal cofactors (Cu, Zn, Mn, Fe)
Antioxidant enzymes are characterized by their specific requirements for metallic cofactors to facilitate their catalytic activity. Superoxide dismutase is a primary example, as its different isoforms require metals such as copper, zinc, manganese, or iron to function. These cofactors are essential for the dismutation of superoxide anions into hydrogen peroxide and oxygen. In contrast, other enzymes like catalase function differently.

162. (C) Glutathione disulfide (GSSG) – The active, reduced form of glutathione
The Ascorbate-Glutathione cycle is a complex pathway for detoxifying reactive species. Ascorbate serves as the primary electron donor for ascorbate peroxidase, while glutathione reductase maintain the pool of reduced glutathione. An incorrect pairing identifies glutathione disulfide as the active, reduced form;

however, GSSG is actually the oxidized state. The active, reduced form is represented as GSH, essential for regenerating ascorbate.

163. (C) Complete nuclear degradation
Elastic strain in plants refers to temporary and reversible responses to stress, which are influenced by factors like cell wall composition, turgor pressure, and cytoskeletal integrity. These components allow tissues to deform and return to their original state. Complete nuclear degradation, however, is a sign of irreversible cellular damage or programmed cell death, representing a plastic or lethal change rather than elastic.

164. (A) Water is held tightly to soil particles, reducing availability.
Matric potential is a measure of the force with which water is held by soil particles or other surfaces. In dry soils, the matric potential becomes severely negative, meaning that water is held very tightly and is difficult for roots to extract. This reduced availability forces the plant to lower its own potential to create a gradient for uptake from soil.

165. (A) Sensible heat flux and leaf temperature must increase.
The energy balance of a plant canopy dictates how incoming radiation is dissipated. If net radiation remains constant but stomata close, the latent heat flux from transpiration is significantly reduced. To maintain energy balance, the energy that was used for evaporation must now be partitioned elsewhere, primarily into sensible heat flux. This results in a rapid increase in leaf temperature over time.

166. (A) SLAC1
Stomatal closure is a rapid process triggered by the efflux of ions from guard cells, leading to a loss of turgor. The SLAC1 protein is a specialized anion channel located on the guard cell plasma membrane that is primarily responsible for the efflux of chloride and malate ions. This efflux causes the membrane to depolarize, which then triggers closure to prevent loss.

167. (A) Framework for targeting specific traits
Passioura's yield model serves as a valuable framework in agricultural research for identifying and targeting specific physiological traits to improve crop performance under drought. By breaking down yield into components like transpiration, water use efficiency, and harvest index, the model allows breeders to evaluate which factors are most limiting in a given environment. This structured approach helps in crop development.

168. (A) Traits like deep rooting and cuticular waxes are typical mechanisms.
Dehydration avoidance is a plant strategy focused on maintaining high tissue water potential during periods of environmental drought. Typical mechanisms include morphological traits such as deep rooting systems to access groundwater and the accumulation of thick cuticular waxes to minimize non-stomatal water loss. These adaptations allow the plant to sustain its hydration levels and continue essential metabolic processes, avoiding cellular stress.

169. (D) It is primarily toxic and rapidly degraded under stress.
Trehalose is a non-reducing disaccharide that functions effectively as a compatible solute and protective molecule in plants during abiotic stress. It helps stabilize cellular membranes and proteins, preventing damage from dehydration and extreme temperatures. Additionally, the precursor trehalose-6-phosphate acts as a crucial signaling molecule. Contrary to incorrect assumptions, trehalose is not primarily toxic; rather, it is a beneficial protective compound.

170. (A) Dehydrins – Group II LEA proteins
Dehydrins are a specific sub-family of late embryogenesis abundant proteins, often classified as Group II LEAs. These proteins are highly hydrophilic and intrinsically disordered, meaning they lack a fixed three-dimensional structure in their hydrated state. They accumulate in massive quantities during seed desiccation and in vegetative tissues during drought. Dehydrins are characterized by conserved structural motifs like the characteristic K-segments.

171. (C) Fermentation – Highly efficient ATP production
Waterlogging leads to conditions of hypoxia or anoxia, where oxygen availability is restricted or completely absent. In response, plants may shift from aerobic respiration to fermentative metabolism. While fermentation allows for continued production of energy in the absence of oxygen, it is not highly efficient, yielding

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to its solute potential. This state represents a critical threshold in cellular water relations.

118. (C) Increased net radiation directly drives higher transpiration rates.
Micrometeorological factors significantly influence the rate of transpiration in plants. Net radiation is a primary driver, as it provides the energy required for the evaporation of water from leaf surfaces. Increased radiation levels generally lead to higher transpiration rates, provided water is available. In contrast, factors like high relative humidity or still air increase resistance, which serves to reduce the rate.

119. (C) Guard cells lack chloroplasts entirely.
Guard cell behavior is governed by changes in turgor pressure that dictate stomatal aperture. Swelling of these cells opens the pore, a process facilitated by the radial micellation of microfibrils and water influx driven by a decrease in solute potential. A common misconception is that guard cells lack chloroplasts entirely. In fact, they possess chloroplasts, which providing energy for the movements.

120. (A) WUE – Ratio of biomass produced to water transpired
Water use efficiency is a critical physiological parameter defined as the ratio of biomass produced or carbon fixed to the total amount of water transpired by the plant. This metric is a key component of Passioura's yield model, which helps researchers evaluate how efficiently a crop utilizes resources. High water use efficiency is a desirable trait in breeding programs for drought-prone environments.

121. (D) Complete desiccation survival – Drought escape
Drought responses are categorized into distinct strategies based on plant behavior. Deep rooting is a form of dehydration avoidance, and a rapid life cycle is characteristic of drought escape. Osmotic adjustment is a mechanism for dehydration tolerance. However, surviving complete desiccation is an extreme form of dehydration tolerance, as seen in resurrection plants, rather than drought escape which avoids dry periods.

122. (B) Nitrogenase
The biosynthesis of osmoprotectants involves specific enzymatic pathways that are upregulated during stress. Pyrroline-5-carboxylate synthetase is the key enzyme for proline synthesis, while betaine aldehyde dehydrogenase is required for glycine betaine production. Nitrogenase, however, is an enzyme involved in atmospheric nitrogen fixation and is not directly responsible for the synthesis of compatible solutes like proline or trehalose used for adjustment.

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123. (A) Intrinsically disordered proteins
Late embryogenesis abundant proteins are structurally classified as intrinsically disordered proteins. This means that in their fully hydrated state, they lack a fixed, stable three-dimensional structure and exist as flexible coils. This unique structural property allows them to remain highly soluble and provides flexibility to interact with various cellular components. Upon dehydration, they can fold into alpha-helices to stabilize cellular membranes.

124. (A) Ethylene
During soil waterlogging, the lack of oxygen leads to a rapid increase in the concentration of ethylene within root tissues. This accumulation acts as the primary physiological trigger for the formation of aerenchyma, which involves the programmed death and lysis of specific cortical cells. The resulting gas-filled chambers facilitate the diffusion of oxygen from the shoots to the submerged, oxygen-deprived root tissues.

125. (A) Extracellular ice nucleation
In cold-acclimated plants, survival during freezing temperatures depends on the controlled formation of ice in the extracellular spaces. By promoting extracellular ice nucleation, the plant prevents the formation of lethal ice crystals within the cytoplasm. This process causes a gradual withdrawal of water from the cell, which increases the internal concentration of solutes and lowers the freezing point of the cytosol.

126. (A) They prevent the irreversible aggregation of heat-denatured proteins.
Heat shock proteins provide a significant advantage during thermal stress by acting as molecular chaperones. Their primary role is to bind to denatured proteins, preventing them from forming irreversible toxic aggregates that would disrupt cellular function. By facilitating the proper refolding of these proteins, HSPs maintain cellular proteostasis. This protective

exudation of organic acids such as citrate or malate from the root tips. These organic acids chelate toxic aluminum ions in the rhizosphere, forming stable complexes that cannot enter the root cells. This prevents the ions from damaging the root apical meristem. In contrast, heavy metal detoxification involves phytochelatins.

181. (B) PP2C – Kinase
The core abscisic acid signaling pathway involves several proteins with specific biochemical functions. PYR/PYL proteins act as soluble receptors that bind the hormone, and SnRK2s are protein kinases that serve as positive regulators of the stress response. However, type 2C protein phosphatases such as PP2C are phosphatases rather than kinases. Their primary role is to negatively regulate the pathway via dephosphorylation.

182. (D) Primary mediator of rapid stomatal closure
Cytokinins are versatile hormones that influence various physiological processes during stress, including the regulation of the cell cycle and the delay of leaf senescence. They also play a role in modulating source-sink dynamics. However, cytokinins are not the primary mediators of rapid stomatal closure. That role is performed by abscisic acid, which is the major hormone responsible for inducing stomatal movements.

183. (A) It is a universally destructive ROS causing indiscriminate cellular damage.
The hydroxyl radical is a universally destructive reactive oxygen species that causes indiscriminate damage to almost all biological molecules it encounters. Due to its extreme reactivity, it can rapidly oxidize proteins, lipids, and DNA, leading to severe cellular dysfunction and injury. Unlike some other reactive species, the hydroxyl radical is not typically used as a controlled signaling molecule in the plant.

184. (A) Ascorbate Peroxidase
Ascorbate peroxidase is an essential antioxidant enzyme that neutralizes hydrogen peroxide in various cellular compartments, especially in the chloroplasts. It achieves this by catalyzing the conversion of hydrogen peroxide into water, utilizing ascorbate as a specific electron donor. This reaction is a critical part of the Foyer-Halliwell-Asada cycle, which protects the photosynthetic apparatus from oxidative damage during environmental stress.

185. (A) Scavenging ROS in multiple compartments
A significant advantage of the Ascorbate-Glutathione cycle over catalase is its presence across multiple cellular compartments. While catalase is primarily restricted to peroxisomes, the enzymes and substrates of the Ascorbate-Glutathione cycle are found in chloroplasts, cytosol, and mitochondria. This widespread distribution allows for efficient scavenging of reactive oxygen species directly at their sites of generation throughout the entire plant cell.

186. (A) Alarm phase (Elastic strain)
The alarm phase, also known as the elastic strain phase, describes the initial and fully reversible response of a plant to an applied abiotic stressor. During this stage, the plant undergoes physiological and molecular changes that do not result in permanent damage. If the stress is removed, the plant can return to its original state of growth and functional development.

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187. (A) Decreases solute potential and allows maintenance of turgor.
Active solute accumulation is a key mechanism for osmotic adjustment in plants under stress. By increasing the concentration of dissolved substances within the cell, the plant effectively decreases its solute potential. This change lowers the total water potential, allowing the cell to continue absorbing water from its environment and maintaining turgor pressure despite low external water availability, supporting vital growth functions.

188. (A) It represents the energy consumed to evaporate water during transpiration.
Latent heat flux is an important component of the energy balance in plant canopies. It represents the energy consumed during the process of evaporating water from the leaf surfaces during transpiration. This heat is taken from the leaf, providing an efficient cooling effect that prevents thermal damage and maintains stable leaf temperatures even under intense sunlight and high radiation levels.

189. (C) ABA activates inward-rectifying potassium channels (e.g., KAT1).
Guard cell responses to abscisic acid involve a coordinated series of ion movements to induce stomatal closure. ABA triggers an increase in cytosolic calcium, which then promotes the activation of anion channels like SLAC1. These

225. (A) Alteration of root cytoskeleton and inhibition of elongation
Aluminum toxicity in acidic soils has severe consequences for root health, manifesting as an alteration of the root cytoskeleton and rapid inhibition of root elongation. Toxic aluminum ions interfere with the organization of microtubules and microfilaments within root tip cells, leading to disordered division. This damage results in a stunted, thickened root system that is highly inefficient at taking up water.

226. (A) LMW transitioning to HMW complexes
In the heavy metal detoxification pathway, toxic metal ions are first chelated by phytochelatins in the cytosol, forming low-molecular-weight complexes. As part of the sequestration process, these LMW complexes are transported into the vacuole, where they can transition into high-molecular-weight complexes. This maturation into HMW complexes increases the stability and storage capacity of the metal within the safe vacuolar compartment.

227. (A) SnRK2 kinases are freed from inhibition and become auto-phosphorylated/active.
The immediate result of PP2C phosphatase inhibition by the PYR/PYL/ABA complex is a major shift in the phosphorylation status of the signaling pathway. Under normal conditions, PP2Cs keep SnRK2 kinases inactive. When ABA is present and phosphatases are inhibited, the SnRK2 kinases are freed from negative regulation. They then undergo auto-phosphorylation, which activates them and allows them to relay stress signals.

228. (A) Stress-induced reduction in cytokinin levels facilitates nutrient remobilization during senescence.
Cytokinins are phytohormones whose levels typically decrease in response to stressors like drought or salinity, a change that facilitates the onset of stress-induced leaf senescence. This programmed breakdown of tissues allows the plant to effectively remobilize essential nutrients from older leaves to more critical areas such as developing reproductive organs. Natural reduction in these hormones is a strategic survival mechanism that helps the plant prioritize resources.

229. (D) Singlet oxygen is primarily generated in the mitochondria.
Reactive oxygen species are produced in several cellular compartments and play various roles in signaling and stress responses. A common misconception is that singlet oxygen is primarily generated in the mitochondria; in reality, it is mostly produced in the chloroplasts during photosynthesis, especially under conditions of excess light. Mitochondrial respiration typically serves as a major source for superoxide and peroxide production.

230. (B) Detoxify peroxide and regenerate substrates
The Foyer-Halliwell-Asada cycle is a primary antioxidant pathway in plants that provides a significant advantage during oxidative stress. Its main function is to detoxify hydrogen peroxide while simultaneously regenerating the substrates needed for continued scavenging, such as reduced ascorbate and glutathione. This cycle utilizes the reducing power of NADPH to maintain a functional pool of reduced and active cellular antioxidants.

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heat. This process relies on several components, including the specialized PsbS protein and the de-epoxidation of pigments in the xanthophyll cycle. NPQ is activated by the accumulation of a proton gradient across the thylakoid membrane, which signals that light absorption has exceeded capacity.

199. (D) Phytochromes strictly exist as a single, non-convertible isoform.
Red and far-red light responses are mediated by phytochromes, which exist in two interconvertible isoforms: the red-light-absorbing Pr form and the far-red-light-absorbing Pfr form. Shade from neighboring plants significantly lowers the red to far-red ratio, triggering shade avoidance. A common misconception is that phytochromes exist as a single, non-convertible isoform; in reality, their ability to switch is fundamental.

200. (A) Halophyte – Requires or optimally tolerates high salt
Plants are categorized based on their response to salinity into two main groups. Halophytes are specialized plants that can tolerate or even require high levels of salt for optimal growth and development. They possess advanced mechanisms for ion exclusion and compartmentalization. In contrast, glycophytes are non-tolerant plants that suffer growth inhibition even at relatively low salt concentrations and environmental exposures.

201. (D) SOS2 – Dephosphorylates strictly.
The salt overly sensitive signaling pathway coordinates the plant's response to sodium toxicity through several specific protein components. Salt stress increases cytosolic calcium, which is detected by the sensor SOS3. SOS3 then activates the SOS2 protein kinase. This kinase phosphorylates and activates the SOS1 Na^+/H^+ antiporter at the plasma membrane. An incorrect pairing suggests that SOS2 acts strictly to dephosphorylate.

202. (D) Deliberate concentration of heavy metals strictly in the nucleus.
Heavy metal tolerance involves several mechanisms to prevent cellular damage from toxic ions. These include the exclusion of metals at the root surface and sequestration into the central vacuole. Sequestration into the vacuole effectively isolates toxic metals from the sensitive metabolic pathways of the cytoplasm. A common misconception is that plants deliberately concentrate heavy metals in the sensitive cellular nucleus.

203. (A) Polymerizes glutathione upon activation
Phytochelatin synthase is a key enzyme in the heavy metal detoxification pathway of plants. It is activated by the presence of toxic metal ions such as cadmium in the cytosol. Upon activation, the enzyme catalyzes the polymerization of glutathione into phytochelatins, which are cysteine-rich peptides that can chelate heavy metals. The resulting metal-phytochelatin complexes are then actively transported into vacuoles.

204. (A) PP2C phosphatases
In the abscisic acid signaling pathway, SnRK2 kinases serve as central positive regulators of the stress response. Under non-stress conditions, these kinases are kept in an inactive state through dephosphorylation by type 2C protein phosphatases. When drought stress occurs and ABA levels rise, the hormone binds to its receptors, which then interact with and inhibit the PP2C phosphatases from activity.

205. (A) Acceleration of source-leaf senescence to remobilize nutrients
Severe abiotic stress often leads to a localized degradation of cytokinins in older leaves. This reduction in cytokinin levels is a significant event because it facilitates the acceleration of the senescence program. By promoting the breakdown of chlorophyll in older source leaves, the plant can effectively remobilize essential nutrients to younger, more active tissues or developing seeds during period of adversity.

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206. (A) Photosystem I
The Mehler reaction is a specific process in which electrons are transferred from the photosynthetic electron transport chain directly to molecular oxygen, generating the superoxide radical. This reaction occurs primarily at the reducing side of photosystem I. While it can be seen as a source of oxidative stress, it also serves as an alternative electron sink that dissipates excess excitation energy.

207. (A) Copper and Zinc
Superoxide dismutase is a critical antioxidant enzyme that requires specific metallic cofactors for its catalytic function. The most common form

events lead to the efflux of potassium ions from the guard cells, causing a loss of turgor. A common misconception is that ABA activates inward-rectifying channels.

190. (A) Water Use Efficiency – Defined as yield per unit water transpired
Water use efficiency is a critical agronomic and physiological parameter, defined as the amount of yield or biomass produced per unit of water transpired by the crop. This metric is a central component of Passioura's yield model, which provides a framework for understanding and improving crop productivity in water-limited environments. High water use efficiency is a key target for plant breeders.

191. (D) Osmotic adjustment – Strictly a drought escape mechanism
Drought responses are classified into different strategies based on how they enable survival. Drought escape involves phenological adjustments like a rapid life cycle, while dehydration avoidance focuses on maintaining tissue hydration through traits like deep roots. However, osmotic adjustment is not a drought escape mechanism. Instead, it is an active physiological process that contributes to both avoidance and tolerance strategies.

192. (D) Strong hydrophobic properties causing precipitation.
Effective compatible solutes are characterized by specific biochemical properties that allow them to protect cells during stress. They are typically small molecules with high and stable solubility in water and an absence of net charge at physiological pH levels. Crucially, they are non-inhibitory to enzyme activity. Contrary to incorrect claims, these solutes do not have strong hydrophobic properties that cause precipitation.

193. (A) Fold into helices to stabilize membranes.
Late embryogenesis abundant proteins are intrinsically disordered in hydrated states but undergo structural changes as water availability decreases. In completely dry seeds, these proteins fold into alpha-helical structures. This structural transition is essential for their function, as it allows them to interact with and stabilize cellular membranes and other proteins during extreme desiccation, preventing irreversible damage and aggregation of cellular components.

194. (A) Root cortex
The anatomical formation of aerenchyma tissue is a specialized adaptation to waterlogging that involves the deliberate and programmed breakdown of specific cells. This process occurs primarily within the root cortex, where cortical cells undergo lysis to create large, interconnected gas-filled cavities. These chambers facilitate the diffusion of oxygen from the aerial parts of the plant to the submerged, oxygen-deprived root tissues.

195. (A) Lowers internal freezing to prevent ice
The primary advantage of extracellular ice nucleation during freezing stress is the prevention of lethal intracellular ice formation. By promoting ice growth in the extracellular spaces, the plant causes a controlled withdrawal of water from the cytoplasm through an osmotic gradient. This process effectively lowers the freezing point of the cytosol and increases its solute concentration, which prevents internal contents from freezing.

196. (A) Molecular chaperones
Molecular chaperones are a diverse group of proteins, including many heat shock proteins, that are essential for maintaining cellular proteostasis during environmental stress. Their primary function is to bind to denatured proteins, preventing them from forming irreversible toxic aggregates that would disrupt metabolic processes. Chaperones facilitate the proper refolding of these damaged proteins into their functional shapes, ensuring plant survival and recovery.

197. (A) Energy transfer to ground state oxygen.
During high light stress, singlet oxygen is generated through a physical process of energy transfer within the chloroplasts. When the absorption of light energy exceeds the capacity for photosynthesis, chlorophyll molecules can enter a long-lived triplet state. This excited chlorophyll can then transfer its surplus energy directly to ground-state molecular oxygen, converting it into highly reactive singlet oxygen species.

198. (A) It relies on the PsbS protein and the xanthophyll cycle to dissipate heat.
Non-photochemical quenching is a critical photoprotective mechanism that allows plants to dissipate excess light energy as harmless

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abundant proteins. This motif is characterized by a lysine-rich sequence that is thought to form an amphipathic alpha-helix. The K-segment is essential for the function of dehydrins, as it allows them to interact with and stabilize cellular membranes and proteins.

217. (A) Shift from aerobic respiration to lactic/ethanolic fermentation.
In roots enduring prolonged soil waterlogging, the lack of oxygen prevents normal aerobic respiration, leading to a major metabolic shift. The plant must move to lactic or ethanolic fermentation to maintain energy production. While this pathway is much less efficient, it ensures continued production of minimal energy necessary for survival. Persistent waterlogging and energy deficits can eventually lead to cellular dysfunction.

218. (A) Specialized ice nucleating active (INA) bacteria can promote extracellular freezing.
Ice nucleation during freezing stress is a critical process. In some cases, specialized ice nucleating active bacteria on the leaf surface can promote the formation of ice in the extracellular spaces. This extracellular freezing is advantageous because it prevents lethal ice crystals inside the cytoplasm. As ice forms outside the cell, it draws water out, increasing internal solute concentration and lowering freezing.

219. (A) HSPs act as irreversible inhibitors of cellular metabolism.
Heat stress has multiple detrimental effects, including increasing kinetic energy of membrane lipids and damaging the oxygen-evolving complex. Acquired thermotolerance is a protective response involving de novo synthesis of heat shock proteins. A common misconception is that HSPs act as irreversible inhibitors; in reality, they are molecular chaperones that facilitate folding. By maintaining proteostasis, HSPs support metabolic function during heat stress.

220. (A) D1 protein – Rapidly degraded and resynthesized
High light stress leads to the damage and repair cycle of the photosystem II reaction center. The D1 protein subunit is particularly susceptible to photo-oxidation and is rapidly degraded once it becomes inactivated. To restore photosynthetic function, the plant must continuously resynthesize and insert new D1 proteins into thylakoid membranes. This specialized repair mechanism is essential for mitigating the effects of photoinhibition.

221. (D) PsbS – Active protease degrading D1
Photoprotection involves a variety of pigments and proteins. Violaxanthin is converted to zeaxanthin via the xanthophyll cycle. Non-photochemical quenching is the process by which excess energy is dissipated as heat. A common misconception is that PsbS is an active protease that degrades the D1 protein; in reality, PsbS is a specialized protein that serves as a pH sensor in membranes.

222. (D) Massive accumulation of thick cuticular wax.
Shade avoidance syndrome is a set of developmental responses to low light quality, characterized by stem elongation and a significant increase in specific leaf area. Contrary to incorrect claims, shade-avoiding plants do not typically accumulate thick cuticular waxes. Instead, they invest resources into rapid vertical growth and the expansion of thin leaf surfaces to maximize light capture in competitive canopy environments.

223. (A) It is driven by the gradual, toxic accumulation of Na^+ and Cl^- inside plant cells over time.
The ionic phase of salinity stress is a long-term response that follows the immediate osmotic phase. It is specifically driven by the gradual and toxic accumulation of sodium and chloride ions within plant tissues. Over time, these ions reach concentrations that interfere with essential cellular processes, including protein synthesis. Managing this phase requires efficient mechanisms for ion exclusion and compartmentalization for survival.

224. (A) Phosphorylating and activating the SOS1 Na^+/H^+ antiporter
The SOS2-SOS3 complex is a critical regulatory unit within the salt overly sensitive signaling pathway. SOS3 acts as a calcium sensor that detects stress-induced changes and activates the SOS2 protein kinase. This complex is directly responsible for phosphorylating and activating the SOS1 Na^+/H^+ antiporter on the plasma membrane. This activation triggers the extrusion of toxic sodium ions from the plant cytoplasm.

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(A) Ethephon
(B) Paclobutrazol
(C) Benzyladenine
(D) Indole-3-butyric acid

2021

10. The concept that phytohormones must be synthesized in one specific tissue and transported to a distant target site to exert their effects is currently viewed as:
(A) Strictly accurate for all modern phytohormones found in vascular plants.
(B) Incomplete, as many hormones function locally near their synthesis site.
(C) Relevant only for gaseous hormones like ethylene during fruit ripening.
(D) Applicable exclusively to the transport of abscisic acid during drought.

2013

11. Which standard physiological bioassay is traditionally used to detect and quantify the presence of biologically active cytokinins?
(A) Tobacco pith callus bioassay
(B) Avena coleoptile curvature test
(C) Barley endosperm alpha-amylase assay
(D) Cotton boll abscission test

2018

12. In the Avena coleoptile curvature test, the degree of curvature is directly proportional to the concentration of:
(A) Ethylene
(B) Gibberellin
(C) Auxin
(D) Abscisic acid

2012

13. The standard bioassay for detecting gibberellins involves measuring the induction of alpha-amylase activity in embryoless half-seeds of which crop?
(A) Maize
(B) Rice
(C) Wheat
(D) Barley

2022

14. Which of the following statements regarding the bioassay for abscisic acid is INCORRECT?
(A) It often measures the promotion of stomatal closure in epidermal peels.
(B) It can involve the inhibition of seed germination.
(C) It typically measures the elongation of intact coleoptiles.
(D) It may utilize the inhibition of alpha-amylase synthesis in barley aleurone layers.

2011

15. In the following question, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct option.
Assertion (A): The triple response bioassay is a highly specific method used for detecting the presence of ethylene in dark-grown dicot seedlings.
Reason (R): Ethylene induces a characteristic phenotype in etiolated seedlings consisting of a shortened and thickened hypocotyl, and an exaggerated apical hook.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2017

16. What is a primary limitation of physiological bioassays compared to modern analytical techniques like GC-MS for hormone quantification?
(A) Bioassays cannot distinguish between physiologically active and inactive stereoisomers.
(B) Bioassays require radioactive labeling of the plant material.
(C) Bioassays are fundamentally unable to detect natural hormones.
(D) Bioassays exhibit cross-reactivity and lower absolute quantitative precision.

2018

17. The promotion of hypocotyl elongation in light-grown lettuce or cucumber seedlings is a classical bioassay for:
(A) Gibberellins
(B) Auxins
(C) Cytokinins
(D) Abscisic acid

2014

18. Which of the following is NOT a recognized bioassay for auxin activity?
(A) Split pea stem curvature test
(B) Tomato ovary growth test
(C) Barley aleurone test
(D) Root elongation inhibition test

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CHAPTER 05

Plant Growth Regulators and Plant Development

NODIA

2016

1. Who among the following is credited with the initial biological demonstration of a diffusible growth-promoting substance, later identified as auxin, using oat coleoptiles?
(A) Frits Went
(B) Charles Darwin
(C) Peter Boysen-Jensen
(D) Eiichi Kurosawa

2008

2. Which of the following defines the distinction between a phytohormone and a synthetic plant growth regulator (PGR)?
(A) Phytohormones are synthesized exogenously for research, while synthetic PGRs occur naturally in various plant tissues.
(B) Phytohormones exclusively promote cell division, while synthetic PGRs are designed to act as specific growth inhibitors.
(C) Phytohormones occur naturally in plants, while synthetic PGRs are man-made analogs used to mimic biological functions.
(D) Phytohormones act at exceptionally high concentrations, while synthetic PGRs remain effective in trace cellular amounts.

2006

3. Which of the following compounds is considered a natural phytohormone rather than a synthetic plant growth regulator?
(A) Indole-3-acetic acid
(B) 2,4-Dichlorophenoxyacetic acid
(C) Naphthaleneacetic acid
(D) Kinetin

2009

4. The initial discovery of gibberellins is attributed to the study of the "bakanae" (foolish seedling) disease in rice. Which pathogen was responsible for this disease?
(A) Agrobacterium tumefaciens
(B) Pseudomonas syringae
(C) Fusarium oxysporum
(D) Gibberella fujikuroi

2007

5. The first naturally occurring cytokinin, identified as zeatin, was isolated from the endosperm of which of the following plants?
(A) Nicotiana tabacum
(B) Zea mays
(C) Avena sativa
(D) Arabidopsis thaliana

2015

6. Abscisic acid (ABA) was historically discovered by independent research groups. What were the original names given to this compound before its unified nomenclature?
(A) Kinetin and Zeatin
(B) Phaseic acid and Xanthoxin
(C) Dormin and Abscisin II
(D) Florigen and Vernalin

2007

7. Compared to classical phytohormones, brassinosteroids are uniquely characterized by which of the following chemical properties?
(A) They are gaseous hydrocarbons produced during the fruit ripening process.
(B) They are substituted adenine derivatives that regulate the cell cycle.
(C) They are indole derivatives synthesized from the precursor tryptophan.
(D) They are polyhydroxylated steroid hormones that regulate growth.

2005

8. The acid growth hypothesis was initially formulated to explain the physiological response of cells to which specific phytohormone?
(A) Auxin
(B) Gibberellin
(C) Cytokinin
(D) Ethylene

2023

9. Based on their physiological actions, which of the following synthetic growth regulators is primarily classified as an anti-gibberellin?

of this enzyme found in the plant cytosol is the Cu/Zn-SOD, which contains both copper and zinc in its active site. These metals facilitate the dismutation of superoxide anions into hydrogen peroxide and molecular oxygen, protecting the cell from damage.

208. (A) Alpha-tocopherol prevents the chain reaction of lipid peroxidation.
Lipid-soluble antioxidants are essential for maintaining the integrity of cellular membranes during oxidative stress. Alpha-tocopherol, also known as Vitamin E, is a primary example of such an antioxidant, which is found within the lipid bilayers. It functions by intercepting lipid peroxyl radicals and neutralizing them. This action effectively prevents the self-propagating chain reaction of lipid peroxidation in membranes.

209. (D) Eustress represents a severe, permanently damaging stress.
Plant strain and deformation are concepts used to describe the biological consequences of applied stress. Mild stresses generally induce reversible elastic strain, while more severe stresses can lead to plastic strain, which involves permanent rearrangement. A common misconception is that eustress is permanently damaging; in reality, eustress refers to mild, potentially beneficial stress that can stimulate adaptive and protective biological responses.

210. (A) Matric potential – Significant in dry seeds
Cellular water relations are governed by several key components of water potential. Matric potential represents the effect of water adhering to surfaces and is typically negligible in hydrated tissues, but it becomes highly significant in very dry environments such as seeds. Other components include solute potential, which is always negative in solutions, and pressure potential, which is typically positive in living cells.

211. (D) Thick boundary layer – Increased transpiration rate.
Canopies interact with their environment through physical fluxes influenced by leaf morphology. High leaf temperatures lead to increased sensible heat flux, while stomatal closure reduces latent heat flux. Conversely, high transpiration increases latent flux, providing cooling. A common misconception is that a thick boundary layer increases the transpiration rate; in reality, a thicker layer increases resistance to water vapor loss, decreasing transpiration.

212. (C) High intensity blue light
Stomatal behavior is regulated by variety of signals. Stomatal closure is typically induced by factors such as high vapor pressure deficit and the hormone abscisic acid. These signals trigger the efflux of ions from guard cells. In contrast, blue light is a well-known signal for stomatal opening. High-intensity blue light activates proton pumps in the membrane, leading to an influx.

213. (A) The crop maximizes carbon assimilation per unit of water transpired.
Water use efficiency is a critical physiological trait that represents the plant's ability to fix carbon dioxide while minimizing water loss. A crop characterized by high WUE maximizes carbon assimilation per unit of water transpired. This is often achieved through advanced stomatal control or other adaptations such as high mesophyll conductance. Selecting for high WUE is a major breeding goal.

214. (A) Escape involves accelerated phenology; avoidance maintains hydration.
Drought escape and dehydration avoidance are two distinct strategies for dealing with water scarcity. Drought escape involves phenological adjustments, such as a rapid life cycle, allowing the plant to complete reproductive stages early. In contrast, dehydration avoidance focuses on maintaining tissue hydration through traits like deep roots. While escape avoids the dry period entirely, avoidance enables the plant to endure the drought.

215. (A) Maintain cell turgor and stabilize protein structures.
The accumulation of massive amounts of proline under drought stress is a key physiological response. Proline acts as a compatible solute that lowers the cellular osmotic potential, facilitating the maintenance of cell turgor. Beyond its role in osmotic adjustment, proline also stabilizes protein structures and cellular membranes. By serving as both an osmoprotectant and a chemical chaperone, proline helps the plant.

216. (A) K-segment
The term K-segment classifies a highly conserved structural motif found in dehydrins, which are a sub-family of late embryogenesis

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2023

19. A plant physiologist extracts a substance from young leaves that promotes the retention of chlorophyll in detached oat leaves in the dark. The extracted substance is most likely a:
(A) Cytokinin
(B) Gibberellin
(C) Brassinosteroid
(D) Jasmonic acid

2009

20. Which of the following is the correct pair of a phytohormone and its corresponding classical bioassay?
(A) Auxin – Triple response test
(B) Gibberellin – Tobacco pith callus test
(C) Ethylene – Oat coleoptile curvature test
(D) ABA – Stomatal closure test

2007

21. Jasmonates are derived from which of the following precursor molecules within the plant cell?
(A) The chorismate biosynthetic intermediate.
(B) Alpha-linolenic acid fatty acid.
(C) The L-methionine amino acid.
(D) The L-tryptophan amino acid.

2003

22. Which endogenous growth regulator is primarily known for its role in establishing systemic acquired resistance (SAR) following a pathogen attack?
(A) Brassinosteroid
(B) Jasmonic acid
(C) Salicylic acid
(D) Strigolactone

2002

23. Strigolactones are a class of novel plant hormones that are chemically derived from which biosynthetic pathway?
(A) Isoprenoid pathway via squalene
(B) Shikimic acid pathway
(C) Polyamine biosynthetic pathway
(D) Carotenoid pathway

2022

24. Which of the following is a primary physiological function attributed to endogenous polyamines such as spermidine and spermine?
(A) Retardation of senescence and membrane stabilization.
(B) Promotion of adventitious rooting in the stem cuttings.
(C) Induction of the triple response in etiolated seedlings.
(D) Inhibition of seed germination under osmotic stress.

2017

25. Consider the following statements regarding endogenous polyamines in plants.
I. They are positively charged aliphatic amines at physiological pH.
II. Putrescine is a common precursor for higher-order polyamines.
III. They promote rapid leaf senescence by destabilizing chlorophyll.
Which of the above statement(s) is/are correct?
(A) Statements I and II only
(B) Statements II and III only
(C) Statements I and III only
(D) Statements I, II, and III

2002

26. Which of the following molecules is an endogenous peptide hormone involved in systemic wound signaling in plants?
(A) Zeatin
(B) Systemin
(C) Campesterol
(D) Coronatine

2009

27. Which of the following statements regarding brassinosteroid signaling is INCORRECT?
(A) Receptors are in the nucleus, like animal steroid receptors.
(B) Brassinosteroids are perceived by a plasma membrane-localized receptor kinase called BRI1.
(C) The signaling cascade involves the dephosphorylation of BES1 and BZR1 transcription factors.
(D) BAK1 acts as a plasma membrane-localized co-receptor in the brassinosteroid signaling pathway.

2011

28. In the JA signaling pathway, the active hormone conjugate jasmonoyl-isoleucine (JA-Ile) binds to the SCF-COI1 complex. This binding directly leads to the ubiquitination and subsequent degradation of which repressor proteins?
(A) Aux/IAA proteins
(B) DELLA proteins
(C) JAZ proteins
(D) ARR proteins

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2023

29. The synthesis of salicylic acid in plants can occur via two independent biochemical routes. What are the primary precursors for these two pathways?
(A) Tryptophan and Methionine
(B) Mevalonic acid and Pyruvate
(C) Linolenic acid and Palmitic acid
(D) Chorismate and Phenylalanine

2015

30. A mutation in the D14 receptor gene in rice will most likely result in which of the following phenotypes?
(A) Increased apical dominance
(B) Extreme dwarfism with shortened internodes
(C) Enhanced tillering and shoot branching
(D) Constitutive triple response

2007

31. The primary tryptophan-dependent biosynthetic pathway for Indole-3-acetic acid (IAA) in most plants involves the intermediate:
(A) Indole-3-glycerol phosphate
(B) Indole-3-pyruvic acid (IPA)
(C) Chorismic acid
(D) Tryptamine

2008

32. In the tryptophan-independent pathway of auxin biosynthesis, IAA is synthesized directly from which of the following precursors?
(A) Anthranilate intermediate
(B) Shikimate intermediate
(C) The amino acid phenylalanine
(D) Indole-3-glycerol phosphate

2005

33. The polar transport of auxin from the shoot apex to the roots is predominantly mediated by which class of efflux carrier proteins?
(A) PIN-FORMED (PIN) proteins
(B) AUX1 influx carrier permeases
(C) ABCB type efflux transporters
(D) Aquaporin membrane channels

2011

34. Which of the following synthetic compounds acts as a specific inhibitor of auxin efflux carriers, thereby blocking polar auxin transport?
(A) Aminoethoxyvinylglycine (AVG)
(B) Paclobutrazol
(C) 1-Naphthylphthalamic acid (NPA)
(D) Silver thiosulfate (STS)

2007

35. Match the items in List I with their corresponding descriptions in List II.
List I: (Auxin Components)
P. YUCCA
Q. AUX1
R. ABCB
S. GH3
List II: (Functions/Characteristics)
1. Flavin monooxygenase in IAA synthesis
2. Auxin influx carrier
3. ATP-dependent auxin efflux transporter
4. Conjugation of IAA to amino acids
(A) P-1, Q-2, R-3, S-4
(B) P-2, Q-1, R-4, S-3
(C) P-3, Q-4, R-1, S-2
(D) P-4, Q-3, R-2, S-1

2009

36. According to the chemiosmotic model of polar auxin transport, IAA enters the cell primarily because:
(A) The cell wall space is highly alkaline, promoting the rapid dissociation of indole-3-acetic acid.
(B) ATP-driven pumps actively transport IAAH across the tonoplast and directly into the vacuole.
(C) Plasmodesmata actively pump IAA anions between adjacent cells via a specific symplastic mechanism.
(D) The acidic cell wall keeps a portion of IAA protonated (IAAH), which diffuses across the plasma membrane.

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2003

37. Which of the following is NOT a recognized mechanism for reducing free auxin levels in plant tissues?
(A) Conjugation to amino acids
(B) Retrograde synthesis of IAA back into tryptophan
(C) Conjugation to sugars such as glucose to form esters
(D) Decarboxylation and oxidation to oxindole-3-acetic acid (oxIAA)

2023

38. The synthesis of indole-3-acetaldoxime (IAOx) is a specific branch of tryptophan-dependent auxin biosynthesis primarily found in which plant family?
(A) Poaceae
(B) Fabaceae
(C) Brassicaceae

(D) Solanaceae

2010

39. In a vertically oriented root tip, auxin is redirected laterally in the root cap by columella cells to induce gravitropic curvature. Which PIN protein is primarily responsible for this lateral redirection?
(A) PIN1
(B) PIN2
(C) PIN4
(D) PIN3

2003

40. Which of the following statements regarding auxin conjugation is INCORRECT?
(A) Most of the auxin in a plant exists in a free, unconjugated state.
(B) Conjugated auxins serve as storage forms that can be rapidly hydrolyzed to yield free IAA.
(C) IAA can be conjugated to macromolecules such as glycoproteins.
(D) IAA-aspartate is a primary conjugate targeted for irreversible degradation.

2013

41. The auxin receptor TIR1 is structurally characterized as:
(A) A plasma membrane localized histidine kinase
(B) An F-box protein within an SCF E3 ubiquitin ligase complex
(C) A soluble cytosolic protein with serine/ threonine kinase activity
(D) A membrane-bound G-protein coupled receptor

2022

42. In the absence of high auxin concentrations, Aux/IAA proteins function primarily by:
(A) Directly activating the transcription of early auxin response genes.
(B) Repressing ARF transcription factors through heterodimerization.
(C) Degrading the TIR1 receptor complex
(D) Phosphorylating the plasma membrane H^+-ATPase

2021

43. Which of the following gene families is NOT considered a primary (early) auxin-responsive gene family?
(A) DELLA
(B) Aux/IAA
(C) GH3
(D) SAUR

2017

44. What is the direct consequence of auxin binding to the TIR1 receptor in the nucleus?
(A) It stabilizes the Aux/IAA repressor proteins against proteasomal degradation.
(B) It induces the autophosphorylation of TIR1.
(C) It promotes the TIR1-Aux/IAA interaction, leading to repressor degradation.
(D) It causes TIR1 to act as a primary transcription factor that binds directly to the DNA.

2024

45. Consider the following statements regarding the acid growth hypothesis for auxin-induced cell elongation.
I. Auxin stimulates the activity of plasma membrane H^+-ATPases.
II. Cell wall acidification activates expansin proteins.
III. Expansins hydrolyze covalent bonds in the cellulose microfibrils.
IV. Turgor pressure drives the actual cell expansion after wall loosening.
Which of the above statement(s) is/are INCORRECT?
(A) I and II
(B) III only
(C) I, II and IV
(D) II and IV

2016

46. Auxin functions as "molecular glue" to stabilize the interaction between which two components?
(A) TIR1 and ARF
(B) ARF and Aux/IAA
(C) TIR1 and Aux/IAA
(D) ARF and DNA

2006

47. Expansins mediate cell wall loosening primarily by disrupting:
(A) Covalent linkages between hemicellulose and pectin
(B) Disrupting hydrogen bonds between cellulose and cross-linking glycans
(C) Peptide bonds in structural wall proteins
(D) Cleaving glycosidic bonds within the internal regions of cellulose chains

2016

48. Identify the correct pair representing the auxin perception mechanism.
(A) ARF – Transcriptional repressor degraded

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auxin, adding progressively higher concentrations of cytokinin will result in:
(A) Rapid root formation
(B) Shoot organogenesis
(C) Inhibition of all cell division
(D) Complete senescence of the callus

2008

91. The primary regulatory enzyme committing precursors to abscisic acid (ABA) biosynthesis in higher plants is:
(A) 9-cis-epoxycarotenoid dioxygenase (NCED)
(B) Zeaxanthin epoxidase (ZEP)
(C) ABA aldehyde oxidase (AAO3) enzyme
(D) Short-chain dehydrogenase/reductase (SDR)

2025

92. ABA biosynthesis proceeds via the cleavage of a 40-carbon precursor into a 15-carbon intermediate. What is the 40-carbon direct precursor cleaved by NCED?
(A) Beta-carotene
(B) Lycopene
(C) 9-cis-neoxanthin or 9-cis-violaxanthin
(D) The 40-carbon precursor phytoene

2025

93. The initial steps of ABA biosynthesis, up to the formation of xanthoxin, occur in the:
(A) Cytosol
(B) Endoplasmic reticulum
(C) Mitochondrion
(D) Plastid

2010

94. ABA is transported efficiently throughout the plant under drought stress. Which of the following forms is NOT a biologically active, long-distance transport state of ABA?
(A) Free ABA in the xylem
(B) Free ABA in the phloem
(C) Phaseic acid
(D) ABA-glucose ester (ABA-GE)

2001

95. The conversion of xanthoxin to ABA aldehyde, and subsequently to ABA, takes place in the:
(A) Plastid stroma
(B) Cytosol
(C) Vacuole
(D) Peroxisome

2005

96. The principal mechanism for irreversible enzymatic inactivation of ABA in plants is the hydroxylation of the 8'-methyl group, catalyzed by ABA 8'-hydroxylase. This enzyme is a:
(A) Flavin monooxygenase
(B) Histidine kinase
(C) A soluble iron-dependent dioxygenase
(D) Cytochrome P450 monooxygenase

NODIA

2017

97. Identify the INCORRECT statement regarding phaseic acid (PA).
(A) It retains strong ABA-like activity in inducing stomatal closure.
(B) It is the immediate product formed from the spontaneous rearrangement of 8'-hydroxy-ABA.
(C) It can be further reduced to dihydrophaseic acid (DPA).
(D) Its formation represents a primary catabolic sink for active ABA.

2024

98. ABA-glucose ester (ABA-GE) accumulates in vacuoles and the apoplast. Under sudden osmotic stress, how does ABA-GE rapidly contribute to active ABA pools?
(A) It acts directly as a ligand for the PYR/PYL receptors.
(B) It competitively inhibits the enzyme ABA 8'-hydroxylase.
(C) It is hydrolyzed by beta-glucosidases to release free ABA.
(D) It diffuses passively into guard cells without needing hydrolysis.

2011

99. The dramatic increase in endogenous ABA concentration during soil drying is primarily due to:
(A) De novo synthesis from transcriptional upregulation of NCED genes.
(B) The complete arrest of ABA transport from root tissues to the shoot.
(C) Reversal of the phaseic acid degradation pathway.
(D) Increased uptake of ABA from the soil microbiome.

2021

100. Identify the correct statement regarding the structural requirement for ABA biological activity.
(A) The trans-trans isomer is the naturally active form.
(B) Removal of the carboxyl group enhances its biological activity.

(C) The enzyme GA 20-oxidase
(D) ent-kaurene oxidase

2018

60. Identify the correct statement regarding geranylgeranyl diphosphate (GGPP).
(A) It is a 15-carbon intermediate.
(B) It is synthesized exclusively in the cytosol via the MVA pathway.
(C) Common precursor for gibberellins, carotenoids, and phytol.
(D) It is a metabolic dead-end product in the isoprenoid pathway.

2001

61. The primary soluble receptor for active gibberellins in the plant cell nucleus is:
(A) TIR1
(B) CRE1
(C) PYR1
(D) GID1

2024

62. DELLA proteins act in the gibberellin signaling pathway as:
(A) Fundamental positive regulators of cellular GA responses.
(B) Kinases that phosphorylate the GA receptor
(C) Transcriptional repressors of GA-induced gene expression
(D) E3 ubiquitin ligases targeting GID1 for degradation

2003

63. The F-box protein specifically required for the ubiquitination of DELLA proteins in Arabidopsis is:
(A) TIR1
(B) SLY1
(C) COI1
(D) MAX2 protein

2018

64. In the cereal seed germination process, which of the following is NOT a hydrolytic enzyme typically secreted by the aleurone layer in response to GA?
(A) Alpha-amylase
(B) Protease enzyme
(C) Beta-glucanase
(D) Cellulose synthase

2024

65. Consider the following statements concerning the GA signaling cascade.
I. GA binds to the soluble GID1 receptor in the nucleus.
II. The GA-GID1 complex binds to DELLA repressors.
III. The tripartite complex recruits an SCF E3 ubiquitin ligase.
IV. DELLA proteins are stabilized to activate transcription.
V. DELLA degradation relieves the repression of GA-responsive genes.
Which of the above statement(s) is/are correct?
(A) I, II, III and V
(B) I, II, IV and V
(C) II, III, IV and V
(D) I, III, IV and V

2006

66. During barley seed germination, GA-induced alpha-amylase synthesis is mediated at the molecular level by the upregulation of which critical transcription factor?
(A) ARF1
(B) EIN3
(C) GAMYB
(D) ABI3

2005

67. The exogenous application of GA to a dwarf mutant (such as ga1 in Arabidopsis) rescues the dwarf phenotype. This suggests that the mutation is primarily in:
(A) A GA biosynthesis gene
(B) The GA receptor gene (GID1)
(C) A DELLA repressor gene
(D) The SLEEPY1 gene

2004

68. If a plant possessed a mutant DELLA protein that lacked the specific domain required for GID1 binding, the expected phenotype would be:
(A) A hyper-elongated (tall) plant due to constitutive GA response
(B) A plant with normal growth and enhanced seed dormancy
(C) Rapid flowering independent of photoperiod
(D) A dwarf plant insensitive to exogenous GA

2015

69. Upon binding bioactive gibberellin, the GID1 receptor undergoes a conformational change characterized by:
(A) Cleavage of its N-terminal domain
(B) Closure of an N-terminal lid, creating a DELLA-binding surface
(C) Autophosphorylation of a histidine residue
(D) Dimerization of receptors to form a functional

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ion channel

2024

70. RGA (Repressor of ga1-3) and GAI (Gibberellin Insensitive) are structurally classified as members of the:
(A) MYB transcription factor family
(B) The MADS-box transcription family
(C) GRAS family of regulatory proteins
(D) bZIP transcription factor family

2011

71. Structurally, natural cytokinins are predominantly substituted derivatives of which nucleic acid base?
(A) Guanine
(B) Cytosine
(C) Uracil
(D) Adenine

2015

72. The first and rate-limiting step in cytokinin biosynthesis is catalyzed by isopentenyl transferase (IPT), which typically utilizes which substrates?
(A) ATP/ADP and Dimethylallyl diphosphate (DMAPP)
(B) Tryptophan amino acid and pyruvate molecules
(C) Adenine and Geranyl diphosphate (GPP)
(D) Methionine and ATP

2011

73. The primary site of major cytokinin biosynthesis in a mature, intact plant is generally considered to be the:
(A) Apical meristem of the shoot
(B) Root apical meristem
(C) Expanding cotyledons
(D) Mature leaves

2025

74. Which of the following is an EXCEPTION to the common naturally occurring active cytokinins in higher plants?
(A) trans-Zeatin
(B) Thidiazuron
(C) cis-Zeatin
(D) Isopentenyladenine (iP)

2012

75. Consider the following steps in the pathway for trans-zeatin biosynthesis and degradation.
I. Attachment of DMAPP to ATP/ADP
II. Formation of isopentenyladenine nucleotides (iP-nucleotides)
III. Hydroxylation by cytochrome P450 monooxygenases to form zeatin nucleotides
IV. Cleavage of the side chain by cytokinin oxidase
What is the correct sequential order of these steps?
(A) I - II - III - IV
(B) II - I - IV - III
(C) I - III - II - IV
(D) III - I - II - IV

2018

76. Cytokinin can be reversibly inactivated and stored in plant tissues primarily through conjugation to form:
(A) Zeatin N-glucoside
(B) Zeatin-aspartate
(C) Zeatin O-glucoside
(D) Methyl-zeatin

NODIA

2001

77. Cytokinin oxidase/dehydrogenase (CKX) enzymes irreversibly degrade cytokinins by cleaving the:
(A) Ribose sugar from the adenine ring
(B) The hydroxyl group found in trans-zeatin isomers
(C) Phosphate group from cytokinin nucleotides
(D) N6-isoprenoid side chain from the adenine ring

2009

78. Transport of cytokinins synthesized in the roots to the aerial parts of the plant occurs predominantly through the:
(A) Phloem sieve elements
(B) Symplastic pathways via plasmodesmata
(C) Xylem transpiration stream
(D) Cortical apoplast

2011

79. Identify the INCORRECT statement regarding cis-zeatin.
(A) It is an abundant form of cytokinin in some species like rice and maize.
(B) It exhibits higher biological activity than trans-zeatin.
(C) It is primarily formed through the chemical modification of tRNAs.
(D) It is an isomer of trans-zeatin, differing in the geometry of the double bond in the side chain.

2024

80. Agrobacterium tumefaciens induces crown gall tumors in plants by inserting T-DNA into the

plant genome. This T-DNA carries a gene (tmr) that encodes for an enzyme directly involved in the synthesis of which hormone?
(A) Auxin
(B) Ethylene
(C) Gibberellin
(D) Cytokinin

2013

81. The signal transduction pathway for cytokinins is structurally and functionally homologous to which signaling system found in bacteria?
(A) Two-component phosphorelay system
(B) G-protein coupled receptor system
(C) The intracellular tyrosine kinase cascade
(D) Notch signaling pathway

2024

82. The primary cytokinin receptors (e.g., CRE1/AHK4 in Arabidopsis) are characterized as:
(A) Nuclear-localized soluble hormone receptor proteins
(B) Cytosolic serine/threonine kinases
(C) Membrane-localized sensor histidine kinases
(D) Ion channels

2017

83. Upon binding cytokinin, the receptor autophosphorylates and transfers the phosphate group next to which intermediary proteins in the cytoplasm?
(A) Arabidopsis Histidine Phosphotransfer (AHP) proteins
(B) Type-A ARRs
(C) Type-B ARR transcription factors
(D) Cyclin-dependent kinases (CDKs)

2014

84. Which components of the cytokinin signaling pathway act as the primary positive transcription factors that activate downstream cytokinin-responsive genes?
(A) Type-A ARRs
(B) AHPs
(C) Cytokinin oxidases
(D) Type-B ARRs

2018

85. In the following question, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct option.
Assertion (A): Cytokinin is essential for progressing through the cell cycle, specifically for the G1 to S phase transition.
Reason (R): Cytokinins upregulate the expression of D-type cyclins (e.g., CycD3), which activate cyclin-dependent kinases required for cell cycle progression.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2010

86. The localized application of cytokinin to a mature yellowing leaf can create a "green island" and delay senescence. This physiological phenomenon is famously known as the:
(A) The triple response effect
(B) Acid growth effect
(C) Richmond-Lang effect
(D) Climacteric rise

2013

87. Identify the INCORRECT pair regarding cytokinin signaling components.
(A) AHP – Phosphotransfer protein
(B) Type-A ARR – Negative regulator
(C) Type-B ARR – Positive transcription factor
(D) CRE1 – Soluble nuclear receptor

2024

88. Type-A ARRs differ fundamentally from Type-B ARRs in that Type-A ARRs:
(A) They lack a DNA-binding domain and act as negative regulators.
(B) They contain a highly conserved DNA-binding MYB-like domain for transcription.
(C) Are constitutively expressed and strictly localized to the plasma membrane.
(D) Act exclusively in the auxin signaling pathway.

2006

89. If a transgenic plant is engineered to continuously overexpress a dominant-negative form of a Type-B ARR, what morphological outcome is most probable?
(A) Extensive proliferation of lateral shoots
(B) Decreased shoot growth and enhanced root elongation.
(C) The spontaneous formation of crown gall tumors on stems.
(D) Delayed leaf senescence across the entire plant

2019

90. In a tobacco pith callus culture growing on a medium with a fixed optimal concentration of

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(A) Auxin
(B) Cytokinin
(C) Ethylene
(D) ABA

2022

132. The ga1 mutant of Arabidopsis is severely dwarfed and fails to germinate without external treatment. This mutation affects a gene encoding:
(A) DELLA repressor
(B) The GID1 gibberellin receptor.
(C) GA 2-oxidase
(D) ent-copalyl diphosphate synthase

2014

133. Which of the following accurately distinguishes the etr1-1 mutant from the ctr1 mutant in Arabidopsis?
(A) etr1-1 is a constitutive ethylene responder, while ctr1 is ethylene-insensitive.
(B) etr1-1 is ethylene-insensitive, while ctr1 is a constitutive ethylene responder.
(C) Both are ethylene-insensitive, but etr1-1 affects a kinase and ctr1 affects a receptor.
(D) etr1-1 overproduces ethylene, while ctr1 cannot synthesize ethylene.

2012

134. Which of the following mutants would NOT be expected to exhibit a precocious germination (vivipary) or severely reduced seed dormancy phenotype?
(A) aba1 (zeaxanthin epoxidase mutant)
(B) abi3 (B3 domain transcription factor mutant)
(C) ein2 (ethylene signaling mutant)
(D) nced3 (ABA biosynthesis mutant)

2024

135. In the following question, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct option.
Assertion (A): The sleepy1 (sly1) mutant in Arabidopsis accumulates very high levels of DELLA repressor proteins.
Reason (R): SLY1 encodes the GA receptor GID1, and its absence directly prevents GA binding.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2002

136. A "constitutive response" mutant is defined as one that:
(A) Displays the hormone phenotype even in the hormone's absence.
(B) Only responds to extremely high doses of a hormone.
(C) Fails to respond to a hormone regardless of the concentration applied.
(D) Rapidly degrades the hormone molecule immediately upon perception.

2004

137. Identify the correct pair representing a hormone signaling mutant and its typical phenotype.
(A) pin1 – Ethylene overproduction
(B) cre1 – Cytokinin insensitivity and reduced shoot growth.
(C) abi1 – Markedly enhanced seed dormancy during maturation.
(D) rga/gai double mutant – Severe dwarfism

2019

138. The Arabidopsis ahk2 ahk3 ahk4 triple mutant lacks the three main primary receptors for cytokinin. The most pronounced developmental defect in this mutant is:
(A) Failure of stomatal closure
(B) Severe dwarfism and an extremely small shoot apical meristem.
(C) Massive proliferation of lateral roots and lack of a primary shoot
(D) Constitutive fruit ripening regardless of ethylene levels.

NODIA

2009

139. The diageotropica (dgt) mutant in tomato is highly insensitive to auxin and exhibits a lack of lateral roots. This mutant is widely used to study:
(A) Auxin-mediated gravitropism and organogenesis.
(B) Gibberellin-induced stem elongation
(C) ABA-induced stomatal closure and water conservation.
(D) Ethylene-induced fruit ripening

2007

140. Identify the INCORRECT statement regarding the aux1 mutant.
(A) It is defective in an auxin influx carrier.
(B) It exhibits agravitropic root growth.
(C) It is defective in polar auxin efflux, leading to fused cotyledons.
(D) It can be rescued by applying membrane-permeable synthetic auxins like NAA.

(C) The carbon ring structure must remain fully saturated for activity.
(D) (+)-S-enantiomer of cis-trans ABA is the natural active form.

2021

101. The core cytosolic receptors for ABA are known as:
(A) GID1 proteins
(B) PYR/PYL/RCAR proteins
(C) ETR1 receptor proteins
(D) TIR1 proteins

2007

102. In the absence of ABA, PP2C proteins function by:
(A) Activating SnRK2 kinases via phosphorylation
(B) Binding to ABA receptors to target them for degradation
(C) Negative regulators that dephosphorylate and inhibit SnRK2s.
(D) Opening stomatal ion channels directly at the plasma membrane.

2015

103. When ABA binds to the PYR/PYL/RCAR receptor, the resulting conformational change allows the receptor to tightly bind and inhibit:
(A) SnRK2
(B) SLAC1
(C) CDPK
(D) PP2C

2012

104. Which of the following is ELIMINATED as an active process during ABA-induced stomatal closure?
(A) Influx of potassium ions (K^+) through inward-rectifying channels
(B) Activation of SLAC1 anion channels
(C) Efflux of potassium ions (K^+) through outward-rectifying channels
(D) Alkalinization of the guard cell cytosol

2009

105. Match the items in List I with their corresponding functions in List II.
List I: (ABA Components)
P. PYR/PYL
Q. SnRK2
R. SLAC1
S. KAT1
List II: (Functions)
1. Inward-rectifying K^+ channel inhibited by ABA
2. ABA receptor
3. Kinase that activates anion channels
4. Slow anion channel responsible for Cl^- and malate efflux
(A) P-2, Q-3, R-4, S-1
(B) P-1, Q-4, R-2, S-3
(C) P-3, Q-1, R-4, S-2
(D) P-2, Q-4, R-3, S-1

2010

106. The activation of SLAC1 by SnRK2 kinases directly causes:
(A) Hyperpolarization of the guard cell plasma membrane
(B) Depolarization of the guard cell plasma membrane
(C) Synthesis of starch in the guard cell chloroplasts
(D) Rapid uptake of water into the guard cell vacuole

2016

107. Cytosolic calcium ($Ca^{\{2+\}}$) spikes are critical in ABA-induced stomatal closure. Increased cytosolic $Ca^{\{2+\}}$ leads to the inhibition of:
(A) Inward-rectifying K^+ channels and plasma membrane H^+-ATPases.
(B) Outward-rectifying K^+ channels
(C) Slow-activating SLAC1 type anion channels
(D) Tonoplast aquaporins

2019

108. Which component is NOT positively associated with the reactive oxygen species (ROS) wave that facilitates stomatal closure during ABA signaling?
(A) NADPH oxidases (e.g., RBOHD/F)
(B) Nitric oxide (NO)
(C) Auxin influx carrier AUX1
(D) Hydrogen peroxide (H_2O_2)

NODIA

2011

109. An Arabidopsis mutant lacking all major functional PP2C phosphatases (like ABI1, ABI2) would most likely exhibit which physiological phenotype?
(A) Severe drought susceptibility due to stomata remaining permanently open
(B) Complete inability to synthesize ABA
(C) Uncontrolled shoot branching due to loss of apical dominance.
(D) Constitutive ABA responses, hyper-dormant seeds, and closed stomata.

by proteasome
(B) Aux/IAA – DNA-binding transcription activator
(C) ABP1 – Nuclear localized primary receptor
(D) TIR1 – E3 ubiquitin ligase subunit

2024

49. In rapid auxin responses, the activation of the plasma membrane H^+-ATPase is thought to occur through:
(A) Phosphorylation of the H^+-ATPase via SAUR-regulated phosphatases
(B) De novo synthesis of H^+-ATPase proteins exclusively
(C) Direct binding of the auxin molecule to the H^+-ATPase pump itself
(D) Ubiquitination of the H^+-ATPase by the SCF-TIR1 complex

2001

50. The degradation of Aux/IAA proteins is executed by the:
(A) Lysosome
(B) Cell wall peroxidases
(C) 26S proteasome
(D) Vacuolar proteases

2021

51. The biosynthesis of gibberellins requires the universal isoprenoid precursor isopentenyl diphosphate (IPP). In plants, IPP for gibberellin synthesis is predominantly generated via the:
(A) MEP pathway in the plastid
(B) MVA pathway in the cytosol
(C) Shikimate pathway in the plastid
(D) Malonate pathway in the cytosol

2021

52. The conversion of geranylgeranyl diphosphate (GGPP) to ent-kaurene during gibberellin biosynthesis takes place in the:
(A) Cytosol
(B) Endoplasmic reticulum
(C) Mitochondrion
(D) Plastid

2023

53. The oxidation of ent-kaurene to ent-kaurenoic acid, catalyzed by ent-kaurene oxidase (KO), occurs at the:
(A) The stack of the Golgi apparatus
(B) Plastid envelope membrane
(C) Plasma membrane
(D) Tonoplast

2008

54. Which of the following gibberellins is generally considered biologically inactive or a deactivation product?
(A) GA1
(B) GA3
(C) GA8
(D) GA4

2022

55. Select the correct sequence of subcellular compartments involved in the biosynthesis of active gibberellins from GGPP.
(A) Cytosol → Endoplasmic Reticulum → Plastid
(B) Plastid → Endoplasmic Reticulum → Cytosol
(C) Endoplasmic Reticulum → Plastid → Cytosol
(D) Plastid → Cytosol → Endoplasmic Reticulum

2024

56. The enzymatic deactivation of bioactive gibberellins (e.g., GA1 and GA4) is catalyzed by:
(A) GA 2-oxidase
(B) GA 20-oxidase
(C) GA 3-oxidase
(D) ent-kaurenoic acid oxidase

2011

57. The enzyme that catalyzes the cyclization of GGPP to ent-copalyl diphosphate is:
(A) ent-kaurene synthase
(B) ent-copalyl diphosphate synthase
(C) GA 20-oxidase synthase
(D) Squalene synthase

2015

58. Which of the following statements regarding gibberellin transport is INCORRECT?
(A) GAs are transported in the phloem along with photoassimilates.
(B) GAs can move strictly via polar transport identical to that of auxins.
(C) GAs are transported in the xylem.
(D) Transport of inactive GA precursors to target tissues is a key regulatory mechanism.

2013

59. Application of the synthetic growth retardant CCC (Chlormequat) inhibits plant height primarily by blocking the activity of:
(A) ent-copalyl diphosphate synthase
(B) GA 3-oxidase

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(D) Sulfate ($SO_4^{\{2-\}}$)

2001

121. The ethylene receptors (e.g., ETR1) in plant cells are localized primarily to the:
(A) Outer plasma membrane surface.
(B) Endoplasmic reticulum membrane
(C) Nuclear envelope
(D) Tonoplast

2001

122. Ethylene binding to its receptor strictly requires a transition metal cofactor. Which metal ion is essential for this interaction?
(A) Zinc ($Zn^{\{2+\}}$)
(B) Copper (Cu^{+})
(C) Iron ($Fe^{\{2+\}}$)
(D) Manganese ($Mn^{\{2+\}}$)

2012

123. The role of CTR1 in the ethylene signaling pathway is best described as:
(A) A negative regulator that represses signaling in ethylene's absence.
(B) A positive regulator that translocates to the nucleus
(C) A transcription factor that activates ERF1 expression.
(D) An E3 ubiquitin ligase that degrades EIN3

2018

124. Which critical protein in the ethylene pathway undergoes proteolytic cleavage upon ethylene perception, releasing a C-terminal fragment that enters the nucleus?
(A) ETR1
(B) CTR1
(C) EIN2
(D) EIN3

2014

125. Consider the following statements regarding the transcriptional regulation of the ethylene response.
I. EIN3 and EIL1 are primary transcription factors in the nucleus.
II. In the absence of ethylene, EIN3 is targeted for degradation by the EBF1/EBF2 F-box proteins.
III. Ethylene perception leads to the stabilization of EIN3.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I, II and III

2017

126. The "triple response" of dicot seedlings to ethylene includes all of the following morphological changes EXCEPT:
(A) Inhibition of hypocotyl elongation
(B) Radial swelling of the hypocotyl
(C) Enhanced proliferation of lateral roots
(D) Exaggerated curvature of the apical hook

2010

127. Which statement correctly describes the activation state of ethylene receptors?
(A) The receptors are active in the presence of ethylene and inactive in its absence.
(B) Active in ethylene's absence, activating CTR1 to repress the pathway.
(C) Ethylene binding phosphorylates the receptor to increase kinase activity.
(D) Receptors act solely as channels that release calcium upon ethylene binding.

2009

128. ERF1 (Ethylene Response Factor 1) is a secondary transcription factor. Which of the following is typically NOT a target of ERF1?
(A) Cellulase genes during abscission
(B) A group of pathogenesis-related (PR) defense genes.
(C) Ripening-related genes in climacteric fruits
(D) Photosynthetic light-harvesting complex genes

2018

129. A dominant mutation in the ETR1 receptor gene that prevents ethylene binding will result in a plant that:
(A) Insensitive to ethylene, failing to show the triple response.
(B) Shows a constitutive triple response even in air
(C) Overproduces ethylene gas in massive quantities.
(D) Exhibits early senescence

2011

130. If the CTR1 gene undergoes a loss-of-function mutation, the expected seedling phenotype in dark conditions (without exogenous ethylene) is:
(A) Elongated hypocotyl and no apical hook
(B) Wild-type appearance
(C) Constitutive triple response
(D) Completely albino

2017

131. The Arabidopsis tir1 mutant is characterized primarily by its physiological resistance to:

NODIA

2005

110. The ABA signaling pathway is often described as a "double negative" regulatory system. This is because:
(A) Two distinct receptors must be simultaneously inhibited.
(B) ABA suppresses both auxin and cytokinin synthesis in the root.
(C) The receptor inhibits a repressor (PP2C), releasing a kinase (SnRK2).
(D) SnRK2 kinases degrade both PP2C and the ABA receptor.

2006

111. The Yang Cycle (methionine salvage pathway) is essential for sustained ethylene biosynthesis because it:
(A) Provides the ATP necessary for ACC synthase activity.
(B) Recycles the methylthio group of SAM, maintaining the methionine pool.
(C) Converts ethylene back into an inactive gaseous state for storage.
(D) Degrades toxic byproducts of the ACC oxidase reaction.

2011

112. The rate-limiting and primary regulated step in the biosynthesis of ethylene is catalyzed by:
(A) Methionine adenosyltransferase
(B) ACC oxidase (ACO)
(C) 1-aminocyclopropane-1-carboxylate N-malonyltransferase
(D) ACC synthase (ACS)

2010

113. ACC oxidase (ACO) catalyzes the conversion of ACC to ethylene. This specific enzymatic reaction strictly requires:
(A) Oxygen (O_2) and ascorbate
(B) Nitrogen (N_2) and ATP
(C) Carbon dioxide (CO_2) and NADPH
(D) Hydrogen peroxide (H_2O_2) and FAD

2010

114. Which of the following stress conditions typically does NOT induce a rapid up-regulation of ACC synthase (ACS) and subsequent ethylene burst?
(A) Flooding/Hypoxia
(B) Mechanical wounding
(C) Continuous red light irradiation.
(D) Acute localized pathogen attack.

2025

115. Select the correct sequential order of intermediates in the ethylene biosynthetic pathway.
(A) Methionine → ACC → SAM → Ethylene
(B) SAM → Methionine → ACC → Ethylene
(C) Methionine → SAM → ACC → Ethylene
(D) ACC → SAM → Methionine → Ethylene

2012

116. S-adenosylmethionine (SAM) serves as a branch point in metabolism. In addition to being the precursor for ethylene, SAM is also the direct precursor for the synthesis of:
(A) Gibberellins
(B) Brassinosteroids
(C) Indole-3-acetic acid
(D) Polyamines

2009

117. Post-translational regulation of ACC synthase (ACS) heavily involves:
(A) Cleavage by vacuolar proteases
(B) Phosphorylation by kinases like MPK6, preventing degradation.
(C) Complex glycosylation within the Golgi apparatus lumen.
(D) Reversible oxidation of cysteine residues

2018

118. In flooded roots, the synthesis of ACC continues but its conversion to ethylene is halted. Why?
(A) ACC synthase is inhibited by water.
(B) The Yang cycle enzymes require light.
(C) ACC oxidase requires oxygen, which is deficient in floods.
(D) Ethylene diffuses too rapidly into the surrounding water.

2001

119. Identify the INCORRECT statement regarding the transport and fate of ethylene and its precursors.
(A) Ethylene gas easily diffuses out of plant tissues into the environment.
(B) ACC can be transported via the xylem from waterlogged roots to the shoot.
(C) ACC can be irreversibly conjugated to malonyl-ACC (MACC) to reduce ethylene production.
(D) Ethylene is actively transported long distances via specialized carrier proteins in the phloem.

2012

120. Which byproduct is generated alongside ethylene and CO_2 during the ACC oxidase reaction?
(A) Cyanide (HCN)
(B) Formate
(C) Ammonia (NH_3)

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2004

141. The classic antagonistic crosstalk in the regulation of lateral bud outgrowth (apical dominance) primarily involves which two hormones?
(A) Gibberellin and Abscisic acid
(B) Ethylene and Jasmonic acid
(C) Salicylic acid and Brassinosteroid
(D) Auxin and Cytokinin

2023

142. The synergistic interaction between auxin and gibberellin in promoting stem elongation is partly explained by the fact that auxin:
(A) Directly phosphorylates DELLA proteins for degradation.
(B) Increases the degradation of the GID1 receptor
(C) Upregulating GA 3-oxidase and downregulating GA 2-oxidase.
(D) Competes for the same TIR1 receptor

2007

143. Seed dormancy and germination are controlled by an antagonistic hormonal balance. The most appropriate ratio determining this developmental transition is:
(A) Auxin : Cytokinin
(B) ABA : GA
(C) Ethylene : Jasmonic acid
(D) Salicylic acid : ABA

2012

144. Which process does NOT typically feature antagonistic crosstalk between ethylene and auxin?
(A) Leaf abscission
(B) Apical hook formation in etiolated seedlings
(C) Lateral root emergence
(D) Phototropic curvature of coleoptiles

2009

145. Consider the following statements regarding the crosstalk between strigolactones (SL) and auxin in shoot branching.
I. Auxin produced in the apical bud travels down the stem and upregulates SL biosynthesis genes (MAX3/MAX4).
II. SL acts locally in the axillary bud to repress its outgrowth.
III. Auxin enters the axillary bud directly to activate SL receptors.
IV. SL downregulates PIN efflux carriers, preventing the export of auxin from the bud.
Which of the above statement(s) is/are INCORRECT?
(A) I and II
(B) II and IV
(C) III only
(D) I and IV

2003

146. In plant physiology, "synergism" between two hormones means:
(A) One hormone perfectly replaces the function of the other.
(B) The two hormones compete for the same receptor binding site.
(C) Joint effect is greater than the sum of individual effects.
(D) One hormone blocks the degradation of the other.

2010

147. Identify the correct statement regarding crosstalk in the root apical meristem.
(A) Auxin promotes division in the meristem, while cytokinin promotes differentiation.
(B) Cytokinin upregulates PIN proteins to increase auxin accumulation in the columella.
(C) Ethylene completely replaces the need for auxin in root hair elongation.
(D) ABA and GA act synergistically to maximize the rate of root cap shedding.

NODIA

2005

148. The widely recognized antagonistic crosstalk regulating defense responses against biotrophic versus necrotrophic pathogens primarily involves:
(A) Auxin and Cytokinin
(B) Gibberellin and Brassinosteroid hormone signals.
(C) ABA and Ethylene
(D) Salicylic acid (SA) and Jasmonic acid (JA).

2012

149. In tissue culture, high levels of both auxin and cytokinin (in an approximately equal ratio) will typically induce:
(A) Rapid root formation
(B) Unorganized cell division (callus formation).
(C) Rapid shoot formation
(D) Immediate onset of programmed cell death in the tissue.

2006

150. Glucose signaling often interacts directly with hormonal pathways. High exogenous glucose concentrations can inhibit seed germination and seedling greening by synergistically interacting with which hormone?
(A) GA
(B) Cytokinin

(A) Vivipary (precocious germination on the mother plant).
(B) Deeply dormant seeds that cannot be rescued
(C) A requirement for light to germinate
(D) Seeds completely lacking a functional endosperm.

2003

210. In the malting industry, barley seeds are steeped and then germinated. To ensure uniform and rapid production of alpha-amylase for starch breakdown, the seeds are often artificially treated with:
(A) Ethylene gas
(B) Auxin sprays
(C) Cytokinin
(D) Gibberellic acid.

2013

211. Fruits that exhibit a distinct, sharp spike in respiration rate and a massive burst of ethylene production at the onset of ripening are classified as:
(A) Climacteric
(B) Parthenocarpic
(C) Non-climacteric
(D) Dehiscent

2024

212. In climacteric fruit ripening, "System 1" ethylene refers to basal, autoinhibitory ethylene production. "System 2" ethylene refers to:
(A) Ethylene produced strictly by the leaves
(B) Ethylene that exclusively causes abscission without ripening
(C) Ethylene generated solely by mechanical wounding.
(D) Autocatalytic surge of ethylene driving ripening.

2008

213. Which of the following is a classic example of a non-climacteric fruit?
(A) Apple
(B) Grape
(C) Banana
(D) Tomato

2008

214. Which of the following physiological processes is an EXCEPTION and does NOT typically characterize the ripening of a fleshy climacteric fruit?
(A) Degradation of chlorophyll and synthesis of anthocyanins/carotenoids
(B) Conversion of starches to soluble sugars
(C) Massive lignification of the pericarp cell walls
(D) Softening of the fruit via polygalacturonase and cellulase activity

2017

215. Consider the following statements regarding fruit ripening and post-harvest inhibitors.
I. 1-MCP accelerates ripening by mimicking ethylene.
II. Silver thiosulfate blocks the ethylene receptor.
III. High CO_2 and low O_2 storage environments delay climacteric ripening.
IV. Potassium permanganate is used as an ethylene scrubber in storage facilities.
V. Climacteric fruits must be harvested fully ripe because they cannot ripen off the plant.
Which of the above statement(s) is/are INCORRECT?
(A) I, II and IV
(B) I and V
(C) II, III and V
(D) III, IV and V

2017

216. 1-Methylcyclopropene (1-MCP) is a synthetic gaseous compound used extensively in post-harvest technology. Its mechanism of action is:
(A) Irreversible binding to ethylene receptors, blocking perception.
(B) Competitive inhibition of the ACC synthase enzyme.
(C) Destruction of ethylene gas in the storage atmosphere
(D) Upregulation of polygalacturonase enzymes

2016

217. The use of silver thiosulfate (STS) significantly extends the vase life of cut flowers because the silver ion (Ag^+):
(A) Rapidly degrades all existing ethylene gas in the air.
(B) Replaces copper in the receptor, blocking signaling.
(C) Directly inhibits bacterial growth in the vase water, acting solely as a biocide
(D) Promotes the synthesis of cytokinins in the stem

2025

218. Consider the following physiological events occurring during the climacteric ripening of a tomato fruit.
I. Upregulation of ACS and ACO genes

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2001

161. Apical dominance is primarily maintained by the continuous production and basipetal transport of which hormone from the shoot apex?
(A) Auxin
(B) Cytokinin
(C) Gibberellin
(D) Strigolactone

2013

162. Strigolactones regulate shoot branching by acting as:
(A) Positive regulators that promote axillary bud outgrowth
(B) Transporters of auxin into the axillary bud
(C) Negative regulators that inhibit axillary bud outgrowth
(D) Precursors for cytokinin synthesis in the root

2001

163. The localized application of which hormone directly to an inhibited axillary bud is most likely to release it from apical dominance?
(A) Cytokinin
(B) Auxin
(C) Gibberellin
(D) ABA

2005

164. In the integration of hormonal signals for bud outgrowth, the transcription factor BRC1 (BRANCHED1) acts as a central hub within the bud. BRC1 function is:
(A) To promote bud outgrowth when activated by cytokinins
(B) To synthesize auxin within the bud
(C) Directly degrade the strigolactone receptors within the bud.
(D) Arrest bud growth; upregulated by strigolactones, downregulated by cytokinins.

2003

165. Consider the following physiological events that occur immediately following the decapitation of a shoot apex.
I. Polar auxin transport down the main stem ceases.
II. Auxin levels in the vicinity of the axillary buds drop significantly.
III. Local biosynthesis of cytokinins in the node decreases.
IV. Strigolactone synthesis in the roots is upregulated.
V. Axillary buds initiate growth.
Which of the above statement(s) is/are correct?
(A) I, II and V
(B) II, III and IV
(C) I, III and V
(D) I, IV and V

2007

166. Decapitation of the shoot apex mechanically removes the primary source of auxin. If an exogenous agar block containing IAA is immediately applied to the decapitated stump, the expected result is:
(A) Rapid outgrowth of axillary buds
(B) Immediate abscission of all leaves
(C) Continued suppression of axillary buds
(D) Reversal of gravitropism

2007

167. According to the auxin canalization hypothesis for shoot branching, for an axillary bud to successfully grow out into a branch, it must:
(A) Import large quantities of auxin directly from the main stem.
(B) Synthesize sufficient ethylene to override BRC1.
(C) Degrade all its internal PIN efflux carrier proteins within the bud.
(D) Establish its own polar auxin stream and export auxin to the stem.

NODIA

2004

168. The highly branched phenotype of Arabidopsis max mutants and pea rms mutants demonstrates that these genes are primarily involved in the synthesis or perception of:
(A) Strigolactone
(B) Auxin
(C) Cytokinin
(D) Brassinosteroid

2005

169. Under dense canopy shade (low Red/Far-Red light ratio), shade avoidance responses generally lead to:
(A) Increased lateral branching to capture more light
(B) Enhanced apical dominance and branching suppression.
(C) Decreased apical dominance
(D) Production of thicker, shorter stems during development.

2006

170. High nitrogen availability in the soil promotes tillering and shoot branching primarily by altering hormonal balances. Specifically, it leads to:

(A) Increase photosynthetic rate in the remaining leaves
(B) Provide carbon substrates for root growth
(C) Eliminate pathogen-infected tissues from the plant body.
(D) Reduce transpirational surface area to conserve water.

2005

190. Pre-harvest fruit drop in crops like apple and citrus can cause significant yield loss. To prevent this, orchardists commonly apply:
(A) Ethephon
(B) Abscisic acid
(C) Synthetic auxins (e.g., 2,4-D or NAA).
(D) Specific ACC synthase inhibitors.

2002

191. Leaf senescence is not merely a chaotic death process, but a highly ordered, genetically programmed process primarily aimed at:
(A) Rapidly eliminating older tissues to prevent disease
(B) Salvaging and remobilizing nutrients to younger organs or seeds.
(C) Re-synthesizing chlorophyll in the dark
(D) Maximizing the transpirational pull of water through the xylem.

2003

192. Senescence-associated genes (SAGs) are heavily upregulated during leaf senescence. A major functional class of proteins encoded by SAGs are:
(A) Rubisco subunits
(B) Chlorophyll biosynthesis enzymes
(C) Auxin transport proteins
(D) Proteases, lipases, and nucleases

2018

193. The progression of leaf senescence is heavily antagonized and delayed by the application or endogenous synthesis of:
(A) Cytokinin
(B) Abscisic acid
(C) Ethylene
(D) Jasmonic acid

2011

194. Which of the following conditions or hormones is NOT recognized as an accelerator or inducer of leaf senescence?
(A) Ethylene
(B) Extreme shading or darkness
(C) Heavy application of gibberellins.
(D) Exogenous abscisic acid treatment.

2014

195. Consider the following statements regarding programmed cell death (PCD) and senescence in plants.
I. PCD occurs only during the final stages of whole-plant senescence.
II. Xylem tracheary element differentiation strictly requires localized PCD.
III. Senescence is a type of PCD that specifically allows for nutrient remobilization prior to cell death.
Which of the above statement(s) is/are INCORRECT?
(A) I and II
(B) I only
(C) II and III
(D) III only

2024

196. In many crop species, the maturation of seeds induces a rapid senescence of the entire vegetative plant. This phenomenon is termed:
(A) Sequential senescence
(B) Apical dominance
(C) Photoperiodic senescence
(D) Monocarpic senescence

2024

197. Identify the correct statement regarding the role of ABA in senescence.
(A) ABA permanently prevents the degradation of chlorophyll.
(B) ABA promotes senescence primarily under stress like drought.
(C) ABA suppresses the expression of all identified SAGs.
(D) ABA's sole function is to maintain leaf greenness during the autumn season.

2017

198. The visible yellowing of leaves during autumn senescence is primarily the direct result of:
(A) Synthesis of blue anthocyanins
(B) Crystallization of various structural cellular proteins.
(C) Chlorophyll degradation unmasking pre-existing carotenoids.
(D) Lignification of the mesophyll cells

2025

199. Transgenic plants engineered to express the IPT gene under the control of a senescence-specific promoter exhibit:
(A) Development of extreme dwarfism in the vegetative growth.
(B) Constitutively closed stomata

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(C) Silver nitrate ($AgNO_3$), an ethylene inhibitor, is used to induce male flowers on genetically female cucumber plants.
(D) Polyamines are the primary universal hormones determining sex across all dioecious angiosperms.

2007

181. The specialized layer of cells at the base of the petiole or pedicel where structural breakdown occurs, leading to organ separation, is called the:
(A) Transition zone
(B) Abscission zone
(C) Cambial zone
(D) Casparian strip

2015

182. According to the auxin gradient theory of abscission, leaf shedding is delayed as long as:
(A) The concentration of auxin in the stem is higher than in the leaf blade.
(B) Ethylene production in the leaf blade remains continuously high.
(C) The flux of auxin from the leaf blade across the zone is maintained.
(D) Auxin transport is completely blocked by inhibitors.

2017

183. The final execution phase of organ abscission involves the breakdown of the middle lamella and primary cell wall. This process is directly catalyzed by the ethylene-induced synthesis and secretion of:
(A) DNA polymerases and helicases
(B) ATPases and expansins
(C) Extracellular amylases and proteases.
(D) Cellulases and polygalacturonases.

2017

184. Which of the following is ELIMINATED as a functional step during the progression of leaf abscission?
(A) Activation of the photosynthetic machinery in the abscission zone
(B) Reduction in polar auxin transport from the leaf blade
(C) Increased sensitivity of the abscission zone cells to ethylene
(D) Lignification and suberization of the protective layer on the stem side

2002

185. Match the phases in List I with their corresponding states in List II.
List I: (Abscission Phases)
P. Leaf Maintenance Phase
Q. Abscission Induction Phase
R. Abscission Execution Phase
S. Post-Abscission Phase
List II: (Hormonal States/Events)
1. High auxin flux from the leaf, low ethylene sensitivity
2. Reduced auxin flux, increased ethylene production
3. Synthesis and secretion of hydrolytic wall enzymes
4. Formation of a protective suberized scar layer
(A) P-1, Q-2, R-3, S-4
(B) P-2, Q-1, R-4, S-3
(C) P-1, Q-3, R-2, S-4
(D) P-3, Q-2, R-1, S-4

2001

186. In agricultural practice, leaf abscission can be artificially accelerated before mechanical harvesting by applying defoliants. These chemicals predominantly function by stimulating the production of:
(A) Auxin
(B) Ethylene
(C) Cytokinin
(D) Gibberellin

2023

187. The sensitivity of the abscission zone to ethylene is critically governed by:
(A) Decline of auxin in the distal side relative to the proximal side.
(B) The local accumulation of abscisic acid within the petiole.
(C) The decline of free auxin levels in the proximal relative to the distal side of the zone
(D) The absolute concentration of gibberellins

2002

188. Which of the following phytohormones is generally considered an inhibitor or delayer of the abscission process?
(A) Ethylene
(B) Abscisic acid
(C) Cytokinin
(D) Jasmonic acid

2013

189. Severe environmental stress, such as prolonged drought, often triggers premature leaf abscission. This physiological response is primarily an adaptation to:

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(C) ABA
(D) Auxin

2007

151. The foundational experiments demonstrating that the balance of auxin and cytokinin controls organogenesis in vitro were conducted by:
(A) Went and Thimann
(B) Darwin and Darwin
(C) Kurosawa and Yabuta
(D) Skoog and Miller

2006

152. According to the classical model of organogenesis in tissue culture, a high ratio of auxin to cytokinin in the culture medium induces the formation of:
(A) Roots
(B) Shoots
(C) Flowers
(D) Somatic embryos

2011

153. Which of the following synthetic auxins is most widely utilized commercially for the induction of adventitious rooting in stem cuttings?
(A) 2,4-D
(B) Indole-3-butyric acid (IBA).
(C) Dicamba
(D) Picloram

2007

154. Plant cells exhibit totipotency, the ability to regenerate a whole plant. Which two hormones are absolutely essential for driving the cell cycle and enabling totipotency in standard tissue culture?
(A) Auxin and Gibberellin
(B) Auxin and Cytokinin
(C) Cytokinin and Ethylene
(D) ABA and Gibberellin

2002

155. Match the items in List I with their corresponding outcomes in List II.
List I: (Tissue Culture Condition)
P. High Auxin, Low Cytokinin
Q. Low Auxin, High Cytokinin
R. Intermediate Auxin, Intermediate Cytokinin
S. 2,4-D application followed by hormone-free medium
List II: (Developmental Outcome)
1. Shoot organogenesis
2. Callus proliferation
3. Somatic embryogenesis
4. Root organogenesis
(A) P-4, Q-1, R-2, S-3
(B) P-1, Q-4, R-3, S-2
(C) P-4, Q-2, R-1, S-3
(D) P-2, Q-3, R-4, S-1

2005

156. Callus tissue can be best described biologically as:
(A) A highly differentiated vascular tissue
(B) A protective layer of dead cork cells
(C) Unorganized mass of actively dividing parenchyma cells.
(D) A specialized secretory gland within the tissue.

2010

157. Identify the INCORRECT statement regarding somatic embryogenesis.
(A) Somatic embryos possess both a functional shoot and root apical meristem.
(B) They develop directly from somatic cells, bypassing the zygote stage.
(C) They are structurally analogous to zygotic embryos but lack a seed coat and endosperm.
(D) High auxin concentrations are required for the maturation phase.

NODIA

2015

158. The application of IBA to the basal cut end of a stem cutting initiates rooting primarily by:
(A) Killing the epidermis to allow water entry
(B) Upregulating cytokinin oxidases locally
(C) Inducing dedifferentiation of parenchyma into a root primordium.
(D) Breaking the metabolic dormancy of pre-existing axillary buds in the stem.

2013

159. In commercial micropropagation, the multiplication stage (Stage II) is optimized to overcome apical dominance and maximize shoot proliferation. This is achieved by supplementing the medium with high concentrations of:
(A) Auxins
(B) Cytokinins
(C) Gibberellins
(D) ABA

2007

160. Identify the correct pair of PGR and its typical major role in plant tissue culture.
(A) Naphthaleneacetic acid (NAA) – Induction of flowering in vitro
(B) Gibberellic acid (GA3) – Callus induction
(C) Paclobutrazol – Somatic embryo induction
(D) Benzylaminopurine (BAP) – Shoot multiplication

(C) Immediate shedding of all flowers
(D) Markedly delayed leaf senescence (stay-green phenotype).

2018

200. Identify the INCORRECT statement regarding cellular dismantling during leaf senescence.
(A) Mitochondria are destroyed very early, halting all cellular respiration before nutrient export begins.
(B) Chloroplasts are typically the first organelles to be dismantled.
(C) The nucleus remains structurally intact and transcriptionally active until the very late stages of senescence.
(D) Autophagy plays a crucial role in the recycling of cellular contents.

2015

201. The transition between seed dormancy and germination in many species is controlled by the dynamic balance of:
(A) Auxin and Ethylene
(B) Abscisic acid (ABA) and Gibberellin (GA).
(C) Cytokinin and Brassinosteroid
(D) Salicylic acid and Jasmonic acid

2021

202. The agricultural practice of stratification, used to break seed dormancy in many temperate woody species, involves exposing the seeds to:
(A) Repeated cycles of wetting and drying
(B) Prolonged periods of cold, moist conditions.
(C) Acid scarification
(D) Exposure to continuous intense far-red light.

2009

203. Primary dormancy is established during seed maturation on the mother plant. In contrast, secondary dormancy is defined as:
(A) Dormancy induced after seed shed, triggered by environment.
(B) Dormancy caused strictly by a hard, impermeable seed coat.
(C) Dormancy that occurs only in the radicle, while the cotyledons are free to expand.
(D) Total inability to germinate due to genetic embryo death.

2014

204. Which of the following is ELIMINATED as a mechanism of seed scarification?
(A) Mechanical abrasion of the seed coat with sandpaper
(B) Passing seeds through the digestive tract of an animal
(C) Soaking the seed in a low concentration of GA3
(D) Chemical breakdown of the seed coat using concentrated sulfuric acid

2022

205. Consider the following statements concerning the hormonal regulation of seed dormancy.
I. ABA accumulates during the seed maturation phase to enforce primary dormancy.
II. De novo synthesis of GA is required to initiate the germination process.
III. The ABA/GA ratio dictates the germination status rather than absolute hormone levels.
IV. High GA levels during seed development lead to deeper primary dormancy.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) I, II and III
(C) II, III and IV
(D) I, III and IV

2017

206. The gradual loss of seed dormancy that occurs during prolonged storage under dry, ambient conditions is known physiologically as:
(A) Stratification
(B) After-ripening
(C) Scarification
(D) Vernalization

2012

207. During the cold stratification of dormant apple seeds, the primary internal biochemical change that overcomes dormancy is:
(A) A dramatic increase in ABA levels and a decrease in GA levels
(B) Decreased ABA coupled with increased GA biosynthesis.
(C) The complete degradation of the seed coat
(D) Accumulation of high levels of various endogenous auxins.

2015

208. Which of the following factors does NOT typically break or help overcome bud dormancy in deciduous fruit trees?
(A) Accumulation of chilling hours during winter
(B) Application of hydrogen cyanamide
(C) Pruning or mechanical injury
(D) Application of high doses of ABA

2019

209. A mutation causing a severe defect in the ABA biosynthetic enzyme NCED during embryogenesis would most likely result in:

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(A) Permanent stem bending near ground level due to wind or rain.
(B) The premature dropping of seeds
(C) The failure of seeds to germinate in cold soil
(D) Systemic fungal infection of the vascular transport system.

2004

228. Match the synthetic plant growth regulator in List I with its major commercial application in List II.
List I: (Growth Regulator)
P. Ethephon
Q. 1-Naphthylacetic acid (NAA)
R. Gibberellic acid (GA3)
S. Trinexapac-ethyl
List II: (Commercial Application)
1. Prevention of pre-harvest fruit drop in apples
2. Acceleration of sugarcane ripening and ripening of tomatoes
3. Increasing bunch length and berry size in seedless grapes
4. Growth reduction in turfgrass to reduce mowing frequency
(A) P-2, Q-1, R-3, S-4
(B) P-1, Q-2, R-4, S-3
(C) P-3, Q-4, R-1, S-2
(D) P-2, Q-3, R-1, S-4

NODIA

2001

229. In commercial turfgrass management, products containing trinexapac-ethyl or paclobutrazol are routinely applied to:
(A) Completely kill grassy weeds
(B) Reducing mowing frequency and enhancing density by limiting elongation.
(C) Promoting rapid, continuous vertical growth of the grass.
(D) Induce rapid flowering of the turf species

2012

230. Identify the INCORRECT statement regarding the herbicidal action of synthetic PGRs.
(A) 2,4-D is selectively toxic to dicots while sparing most monocots.
(B) Auxinic herbicides cause massive overproduction of ethylene, leading to epinasty and tissue damage.
(C) Atrazine and Glyphosate are both classified functionally as synthetic auxins.
(D) High doses of synthetic auxins disrupt the phloem, effectively starving the root system.

****

II. System 2 autocatalytic ethylene burst
III. Activation of ripening-related transcription factors (e.g., RIN)
IV. Cell wall softening, pigmentation changes, and flavor development

What is the correct physiological sequence of these events?
(A) I - II - III - IV
(B) III - I - II - IV
(C) II - I - IV - III
(D) I - III - II - IV

2010

219. The Flavr Savr tomato was engineered for delayed ripening and increased shelf life by:
(A) Expressing antisense RNA to downregulate PG activity.
(B) Overexpressing the ETR1 ethylene receptor protein.
(C) Deleting the ACC synthase gene entirely
(D) Introducing a bacterial ACC deaminase gene

2010

220. Controlled Atmosphere (CA) storage relies on altering the gaseous environment to extend the shelf life of apples. CA conditions generally involve:
(A) 0% oxygen and 0% carbon dioxide
(B) 1–3% oxygen and 1–5% carbon dioxide
(C) 5–10% oxygen and 0.03% carbon dioxide
(D) 21% oxygen and 0.03% carbon dioxide

2006

221. The widely used synthetic growth retardant paclobutrazol exerts its dwarfing effect by directly inhibiting:
(A) ACC synthase in the ethylene biosynthesis pathway
(B) TIR1 auxin receptor molecular binding.
(C) Isopentenyl transferase in cytokinin synthesis
(D) ent-kaurene oxidase in the GA pathway.

2005

222. Chlormequat chloride reduces stem elongation in cereal crops primarily by inhibiting the cyclization of geranylgeranyl diphosphate to ent-copalyl diphosphate. This blocks the early stages of:
(A) Abscisic acid synthesis
(B) Brassinosteroid synthesis
(C) Gibberellin synthesis
(D) Auxin synthesis

2024

223. Synthetic auxins like 2,4-D and Dicamba are used as effective herbicides against broadleaf weeds because:
(A) They rapidly degrade in the plant, depriving it of essential auxin.
(B) Stable accumulation causing uncoordinated growth and vascular disruption.
(C) They specifically block photosynthesis in dicots.
(D) Directly destroying the root apical meristem by competitive inhibition.

2015

224. Which of the following is an EXCEPTION to the intended agricultural benefits of applying synthetic anti-gibberellins?
(A) Prevention of lodging in small grains
(B) Maintenance of compact growth in ornamental potted plants
(C) Reduction of vegetative shoot growth to enhance fruit set in orchards
(D) Increased intermodal elongation and enhanced biomass of forage crops

2021

225. In the following question, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct option.
Assertion (A): Prohexadione-calcium is an effective agricultural growth retardant that lowers the levels of biologically active gibberellins.
Reason (R): Prohexadione-calcium structurally mimics 2-oxoglutarate and competitively inhibits GA 3-oxidase, blocking the final conversion to active GA1/GA4.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2002

226. Compounds that specifically interfere with the biosynthesis or action of gibberellins are collectively grouped in horticulture as:
(A) Defoliants
(B) Ripening agents
(C) Growth retardants
(D) Parthenocarpic agents

2011

227. The application of growth retardants to wheat or barley crops is primarily intended to prevent "lodging". Lodging refers to:

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(A) Increased strigolactone synthesis
(B) Increased root-derived cytokinins and decreased strigolactone exudation.
(C) Decreased auxin transport capacity
(D) Enhanced synthesis of the hormone ABA within the root tissues.

2004

171. The mobile signal responsible for transmitting the photoperiodic floral stimulus from leaves to the shoot apical meristem is identified as:
(A) FLOWERING LOCUS T (FT) protein.
(B) Vernalin
(C) The CONSTANS (CO) protein.
(D) Gibberellic acid

2003

172. In many rosette plants (long-day plants) such as spinach or cabbage, application of which hormone can substitute for the long-day requirement and induce "bolting" and flowering?
(A) Cytokinin
(B) Auxin
(C) Gibberellin
(D) Ethylene gas.

2012

173. In cucurbits (e.g., cucumber and melon), sex expression is highly malleable. Exogenous application of ethylene (or ethephon) typically promotes the formation of:
(A) Male flowers
(B) Hermaphroditic flowers
(C) Sterile flowers
(D) Female flowers

2015

174. Parthenocarpy (the development of fruit without fertilization) can be artificially induced in many horticultural crops by the application of:
(A) ABA and Ethylene
(B) Cytokinins and Brassinosteroids
(C) Auxins and Gibberellins
(D) Jasmonic acid and Salicylic acid

2023

175. In the following question, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct option.
Assertion (A): In certain dioecious species like spinach and hemp, the application of gibberellins strongly promotes the formation of male flowers.
Reason (R): Gibberellins invariably suppress the development of stamen primordia across all plant species.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2015

176. Vernalization is the promotion of flowering by prolonged exposure to cold. The primary epigenetic target of vernalization in Arabidopsis, which is stably repressed by cold, is:
(A) LEAFY (LFY)
(B) APETALA1 (AP1)
(C) PHYTOCHROME B (PHYB)
(D) FLOWERING LOCUS C (FLC).

2021

177. Identify the correct statement concerning hormone dynamics during natural fruit set and early fruit development.
(A) Developing seeds provide auxin and GA to drive fruit tissue expansion.
(B) Successful fertilization leads to an immediate drop in auxin and GA levels in the ovary.
(C) High levels of ABA and ethylene are required to initiate initial ovary cell divisions.
(D) Parthenocarpic fruits generally contain much higher levels of mature seeds than non-parthenocarpic fruits.

2014

178. The "strawberry receptacle" experiment conducted by Nitsch demonstrated that:
(A) Ethylene is required for strawberry ripening.
(B) Exogenous gibberellins inhibit the expansion of the strawberry receptacle.
(C) Seed removal halts receptacle growth; restored by exogenous auxin.
(D) Cytokinins synthesized in the roots are the sole drivers of fruit expansion.

2006

179. Pineapple is unique in its response to plant hormones for flowering. Commercial synchronous flowering in pineapple fields is routinely achieved by spraying:
(A) Ethephon
(B) Abscisic acid (ABA).
(C) Gibberellic acid
(D) Paclobutrazol

2022

180. Identify the INCORRECT statement regarding the hormonal regulation of sex expression.
(A) Ethylene promotes femaleness in cucumber.
(B) Gibberellin promotes maleness in cucumber.

NODIA

ANSWERS

1. (A) Frits Went
Frits Went performed seminal experiments using oat coleoptiles to demonstrate the presence of a diffusible growth-promoting substance. He showed that this chemical, later named auxin, could diffuse into agar blocks and induce curvature when placed asymmetrically on decapitated stumps. This work established the first quantitative bioassay for plant hormones and confirmed the chemical nature of phototropic growth responses.

2. (C) Phytohormones occur naturally in plants, while synthetic PGRs are man-made analogs used to mimic biological functions.
Phytohormones are endogenous signaling molecules synthesized by plants to regulate physiological processes at very low concentrations. In contrast, synthetic plant growth regulators are industrial compounds designed to replicate or inhibit these natural activities for agricultural and research purposes. While they share functional pathways, the fundamental distinction lies primarily in their biological origin and chemical synthesis in laboratories.

3. (A) Indole-3-acetic acid
Indole-3-acetic acid is the primary, naturally occurring auxin found in most vascular plants. While substances like 2,4-D and naphthaleneacetic acid exhibit auxin-like activity, they are synthetic analogs produced chemically. Kinetin is also a synthetic cytokinin originally discovered as a degradation product of DNA. Natural hormones are defined specifically by their endogenous synthesis within living plant tissues.

4. (D) Gibberella fujikuroi
The discovery of gibberellins originated from research into the foolish seedling disease of rice, characterized by excessive stem elongation. This pathological condition was caused by the fungal pathogen Gibberella fujikuroi. Japanese scientists later isolated the active compounds from fungal secretions and identified them as gibberellins, which were subsequently found to be natural hormones produced by all higher plants.

5. (B) Zea mays
Zeatin was the first naturally occurring cytokinin to be identified and chemically characterized. It was originally isolated from the immature endosperm of maize, also known as Zea mays, which provided a rich source of the compound. This discovery was pivotal because it confirmed that cytokinins are endogenous plant hormones rather than just synthetic molecules like the previously discovered kinetin.

6. (C) Dormin and Abscisin II
Abscisic acid was discovered independently by different research teams studying various physiological processes. One group identified a substance promoting bud dormancy and named it dormin, while another group isolated a compound inducing leaf abscission in cotton and named it abscisin II. These compounds were eventually found to be identical, leading to the unified nomenclature known as abscisic acid.

7. (D) They are polyhydroxylated steroid hormones that regulate growth.
Brbrassinolides represent a distinct class of plant hormones characterized by their polyhydroxylated steroidal structure. Unlike gaseous ethylene or indole-derived auxins, these compounds are structurally similar to animal steroid hormones. They play essential roles in promoting cell elongation, vascular differentiation, and pollen tube growth. Their discovery expanded the understanding of hormonal diversity by proving that steroids function as critical growth regulators.

8. (A) Auxin
The acid growth hypothesis explains how auxin induces rapid cell elongation. According to this model, auxin stimulates plasma membrane proton pumps, which acidifies the cell wall space. This lower pH activates wall-loosening enzymes like expansins that disrupt hydrogen bonds between cellulose microfibrils. Consequently, the cell wall becomes more extensible, allowing internal turgor pressure to drive cellular expansion and growth.

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the hydrogen bonds between cellulose microfibrils and cross-linking glycans. This temporary loosening allows the cell wall to expand under the force of turgor pressure without damaging its structural integrity.

46. (C) TIR1 and Aux/IAA
Auxin functions as a "molecular glue" because it occupies a binding pocket between the TIR1 receptor and the Aux/IAA repressor. The hormone molecule directly contacts both proteins, significantly increasing their binding affinity. This structural arrangement is unique because the hormone itself becomes an integral part of the protein-protein interface, leading to the targeted degradation of the repressor in a concentration-dependent manner.

47. (B) Disrupting hydrogen bonds between cellulose and cross-linking glycans
Expansins are unique wall-loosening proteins that do not possess traditional enzymatic cleavage activity. Instead, they function by weakening the non-covalent hydrogen bonds that hold cellulose microfibrils and hemicelluloses together. This action allows the microfibrils to slide past each other during cell expansion. This process is fully reversible and is triggered by the acidification of the cell wall environment following auxin application.

48. (D) TIR1 – E3 ubiquitin ligase subunit
TIR1 is the primary receptor for auxin and functions as an integral F-box subunit of the SCF E3 ubiquitin ligase complex. It recognizes and binds to Aux/IAA repressor proteins only in the presence of auxin. This specific interaction leads to the degradation of the repressors, which is the central event in auxin perception. ARFs are transcription factors, not repressors that are degraded.

49. (A) Phosphorylation of the H^+-ATPase via SAUR-regulated phosphatases
Rapid auxin-induced acidification involves the activation of the plasma membrane H^+-ATPase. This occurs through a signaling pathway where auxin induces the expression of SAUR genes. SAUR proteins then bind to and inhibit PP2C-D type phosphatases, which would otherwise dephosphorylate the H^+-ATPase. By inhibiting these phosphatases, the H^+-ATPase remains in a phosphorylated, active state, leading to increased proton extrusion into the cell wall.

50. (C) 26S proteasome
The degradation of Aux/IAA repressor proteins is a strictly regulated process that occurs within the 26S proteasome. After being tagged with ubiquitin by the SCF-TIR1 complex in the presence of auxin, these proteins are recognized and broken down by this massive multi-protein protease complex. This degradation is essential for the activation of auxin-responsive genes and the subsequent physiological changes in the plant.

NODIA

51. (A) MEP pathway in the plastid
In higher plants, the isopentenyl diphosphate required for gibberellin biosynthesis is primarily produced via the methylerythritol phosphate pathway located in the plastids. While the mevalonate pathway in the cytosol produces IPP for other isoprenoids, the plastidial MEP pathway is the major source for precursors of gibberellins, carotenoids, and the phytol side chain of chlorophyll. This compartmentalization is key to regulating different isoprenoid products.

52. (D) Plastid
The initial stages of gibberellin biosynthesis take place within the plastid. This includes the conversion of geranylgeranyl diphosphate into ent-kaurene through a two-step cyclization process catalyzed by specific synthases. This early part of the pathway is highly regulated and is sequestered from the later oxidation steps that occur in different cellular compartments, ensuring the precise control of active hormone production.

53. (B) Plastid envelope membrane
Following its synthesis in the plastid stroma, ent-kaurene is oxidized to ent-kaurenoic acid. This reaction is catalyzed by ent-kaurene oxidase, which is a cytochrome P450 monooxygenase localized to the plastid envelope membrane. This step represents a transition in the pathway as the intermediates move from the interior of the plastid toward the endoplasmic reticulum for further modifications into bioactive gibberellins.

54. (C) GA8
While GA1, GA3, and GA4 are well-known biologically active gibberellins that promote growth, GA8 is an inactive form. It is produced from the 2-beta-hydroxylation of bioactive GA1, a reaction that serves to deactivate the hormone and terminate its signaling. Measuring the ratio

18. (C) Barley aleurone test
The barley aleurone test is a specific bioassay for gibberellins, which induce alpha-amylase synthesis in the aleurone layer during germination. In contrast, auxin activity is traditionally measured using tests such as the split pea stem curvature test, the tomato ovary growth test, and the root elongation inhibition test. These auxin assays rely on the hormone's ability to stimulate or inhibit growth.

19. (A) Cytokinin
Cytokinins are well known for their ability to delay senescence and promote nutrient mobilization. One of their most characteristic effects is the retention of chlorophyll in detached leaves, even when kept in darkness. This phenomenon, often called the Richmond-Lang effect, involves the stabilization of chloroplast membranes and the inhibition of chlorophyll-degrading enzymes, maintaining the green color of the leaf tissue.

20. (D) ABA – Stomatal closure test
Abscisic acid is a critical stress hormone that triggers the closure of stomata to prevent water loss during drought. The stomatal closure bioassay uses epidermal peels to measure this response, making it a classic test for abscisic acid activity. Other pairs are incorrect as the triple response is for ethylene, the callus test is for cytokinin, and coleoptile curvature is for auxin.

21. (B) Alpha-linolenic acid fatty acid.
Jasmonates are lipid-derived signaling molecules synthesized through the octadecanoid pathway. The process begins with the release of alpha-linolenic acid from plastid membranes. This fatty acid undergoes a series of enzymatic reactions involving lipoxygenase and other enzymes to form jasmonic acid. These compounds are essential for regulating plant defense against herbivores and necrotrophic pathogens, as well as various developmental processes.

22. (C) Salicylic acid
Salicylic acid is the primary endogenous regulator responsible for establishing systemic acquired resistance. Following a localized pathogen attack, salicylic acid levels increase, triggering a signaling cascade that prepares distant, uninfected parts of the plant for potential secondary infections. This systemic response involves the upregulation of pathogenesis-related genes and provides broad-spectrum, long-lasting immunity against a wide variety of fungal, bacterial, and viral pathogens.

NODIA

23. (D) Carotenoid pathway
Strigolactones are a relatively new class of plant hormones that are chemically derived from carotenoid precursors. They are synthesized via the cleavage of beta-carotene by carotenoid cleavage dioxygenase enzymes. These molecules play dual roles, acting as endogenous signals to inhibit shoot branching and as exogenous signals in the rhizosphere to stimulate the germination of parasitic weeds and mycorrhizal fungi.

24. (A) Retardation of senescence and membrane stabilization.
Polyamines, such as spermine and spermidine, are small aliphatic cations found in all plant cells. Their primary physiological functions include the retardation of leaf senescence and the stabilization of cellular membranes and nucleic acids. They achieve this by binding to negatively charged molecules, protecting them from degradation. Polyamines are also involved in stress tolerance, cell division, and various aspects of development.

25. (A) Statements I and II only
Polyamines are positively charged aliphatic amines at physiological pH, which allows them to interact with negatively charged cellular components like DNA and proteins. Putrescine serves as a fundamental building block for the synthesis of higher-order polyamines like spermidine. Contrary to the third statement, polyamines typically act to delay senescence and stabilize chlorophyll rather than promoting its degradation or the aging process.

26. (B) Systemin
Systemin is a small peptide hormone found in many plant species, particularly in the Solanaceae family. It serves as a primary signal for the systemic wound response. When a plant is damaged by herbivory, systemin is released and travels through the phloem to trigger the synthesis of jasmonic acid in distant tissues. This coordinate response leads to the production of protease inhibitors.

27. (A) Receptors are in the nucleus, like animal steroid receptors.
Brassinosteroid signaling differs significantly from animal steroid signaling because the

receptor binds to a bioactive gibberellin and a DELLA protein, SLY1 recognizes the DELLA protein and targets it for ubiquitination. This marks the DELLA repressor for degradation by the 26S proteasome.

64. (D) Cellulose synthase
During the germination of cereal seeds, gibberellins produced by the embryo stimulate the aleurone layer to produce and secrete various hydrolytic enzymes. These include alpha-amylase for starch breakdown, proteases for protein digestion, and beta-glucanases for cell wall degradation. Cellulose synthase, however, is an enzyme involved in the synthesis of cell wall components during growth and is not a hydrolytic enzyme secreted during the mobilization of endosperm reserves.

65. (A) I, II, III and V
The gibberellin signaling cascade begins with the hormone binding to the GID1 receptor in the nucleus. This complex then binds to DELLA repressor proteins and recruits an SCF E3 ubiquitin ligase. The key outcome is the degradation of DELLA proteins by the 26S proteasome, which relieves the repression of GA-responsive genes. Statement IV is incorrect because DELLA proteins must be degraded, not stabilized, to activate the response.

66. (C) GAMYB
GAMYB is a specific MYB-class transcription factor that is essential for the gibberellin-induced expression of alpha-amylase in cereal aleurone cells. Gibberellin signaling leads to the degradation of DELLA proteins, which otherwise repress GAMYB expression. Once synthesized, the GAMYB protein binds directly to the promoter regions of alpha-amylase genes, activating their transcription and initiating the mobilization of starch reserves during the germination process.

67. (A) GA 1 biosynthesis gene
In Arabidopsis, the ga1 mutant is a well-known dwarf that lacks the ability to produce gibberellins. Because the defect lies in the biosynthetic pathway, the plant still possesses functional receptors and signaling components. Therefore, the application of exogenous gibberellins can bypass the block in synthesis, restoring normal growth and development. This rescue phenotype is a classic way to distinguish biosynthesis mutants from signaling mutants.

68. (D) A dwarf plant insensitive to exogenous GA
If a DELLA protein cannot bind to the GID1 receptor, it can no longer be targeted for degradation, even in the presence of high levels of gibberellin. This mutant protein would constitutively repress growth, resulting in a dwarf phenotype. Because the problem is at the perception level, applying external gibberellin would have no effect, making the plant insensitive to the hormone.

69. (B) Closure of an N-terminal lid, creating a DELLA-binding surface
The binding of bioactive gibberellin to the GID1 receptor causes a dramatic change in its structure. Specifically, an N-terminal flexible extension or "lid" closes over the hormone binding pocket. This closure creates a new hydrophobic surface on the receptor that specifically recognizes and binds to the DELLA domain of repressor proteins. This conformational change is the critical molecular switch that initiates the signaling cascade.

70. (C) GRAS family of regulatory proteins
RGA and GAI are prominent members of the GRAS family of proteins, named after the first three identified members: GAI, RGA, and SCR. These proteins are characterized by a highly conserved C-terminal GRAS domain and a unique N-terminal DELLA domain. While they function as transcriptional regulators, they do not bind directly to DNA but instead interact with other transcription factors to control the expression of gibberellin-responsive genes.

71. (D) Adenine
Cytokinins are a class of plant hormones that are structurally based on the nucleic acid base adenine. They consist of an adenine ring with a specific side chain attached at the N6 position. These side chains can be either isoprenoid or aromatic in nature. The structure of these molecules is fundamental to their ability to bind to specific receptors and regulate processes like cell division and chloroplast development.

72. (A) ATP/ADP and Dimethylallyl diphosphate (DMAPP)
The synthesis of cytokinins begins with the transfer of an isopentenyl group from dimethylallyl diphosphate to the N6 position

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acidic environment of the cell wall keeps a fraction of auxin in its uncharged, protonated form. This lipophilic molecule can diffuse freely across the plasma membrane. Once inside the neutral cytosol, the auxin dissociates into its anionic form, which is then trapped and requires specific carriers for exit.

37. (B) Retrograde synthesis of IAA back into tryptophan
Plants reduce free auxin levels through conjugation to sugars or amino acids and through irreversible oxidation to compounds like oxindole-3-acetic acid. These mechanisms ensure precise control over hormone activity. However, the retrograde synthesis of indole-3-acetic acid back into its precursor tryptophan is not a recognized metabolic mechanism for lowering hormone concentrations, as the biosynthetic steps are generally considered irreversible.

38. (C) Brassicaceae
The synthesis of indole-3-acetaldoxime is a specialized branch of auxin biosynthesis that is particularly prominent in the Brassicaceae family, which includes Arabidopsis. This intermediate is unique because it serves as a common precursor for both indole-3-acetic acid and secondary metabolites such as glucosinolates and camalexin. This metabolic link allows these plants to coordinate their growth with defense responses against pathogens and herbivory.

39. (D) PIN3
Gravitropism in roots depends on the lateral redirection of auxin across the root cap. When a root is placed horizontally, starch-containing statoliths in columella cells settle, triggering the relocation of PIN3 efflux carriers to the lower side of the cell. This causes auxin to accumulate on the lower side of the root, where it inhibits elongation and results in downward curvature.

40. (A) Most of the auxin in a plant exists in a free, unconjugated state.
In reality, the vast majority of auxin within plant tissues is found in conjugated forms, primarily linked to sugars or amino acids. These conjugates serve as inactive storage forms that can be hydrolyzed to release free, bioactive indole-3-acetic acid when needed. Precise regulation of the balance between free and conjugated auxin is crucial for maintaining proper hormone levels throughout development.

41. (B) An F-box protein within an SCF E3 ubiquitin ligase complex
The auxin receptor TIR1 is an F-box protein that serves as a substrate recognition subunit within an SCF E3 ubiquitin ligase complex. It is localized in the nucleus and directly binds to auxin. This binding increases the affinity of TIR1 for its target proteins, the Aux/IAA repressors, leading to their ubiquitination and subsequent degradation by the 26S proteasome system.

42. (B) Repressing ARF transcription factors through heterodimerization.
In the absence of auxin, Aux/IAA proteins act as transcriptional repressors by binding to auxin response factors. This heterodimerization prevents ARFs from activating the expression of auxin-responsive genes. Aux/IAA proteins also recruit co-repressors like TOPLESS to further inhibit gene transcription. When auxin levels rise, these repressors are degraded, allowing ARFs to function as active transcription factors and initiate cellular responses.

43. (A) DELLA
Primary or early auxin-responsive genes are those whose transcription is induced rapidly and directly by the hormone without requiring de novo protein synthesis. Key families include the Aux/IAA, GH3, and SAUR genes. DELLA proteins, however, are transcriptional repressors specifically associated with the gibberellin signaling pathway. While crosstalk between hormones occurs, DELLA is not classified as a primary target of the auxin signaling machinery.

44. (C) It promotes the TIR1-Aux/IAA interaction, leading to repressor degradation.
Auxin acts as a molecular bridge that stabilizes the interaction between the TIR1 receptor and the Aux/IAA repressor proteins. By binding to the pocket of TIR1, auxin facilitates the recruitment of Aux/IAA proteins to the SCF-TIR1 complex. This leads to the ubiquitination and subsequent degradation of the repressors by the 26S proteasome, thereby releasing the inhibition on auxin-responsive gene expression.

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45. (B) III only
The acid growth hypothesis describes how auxin induces cell wall loosening by activating H^+-ATPases and expansins. While expansins are essential for this process, they do not hydrolyze covalent bonds. Instead, they work by disrupting

9. (B) Paclobutrazol
Paclobutrazol is a synthetic growth regulator widely used in agriculture as a potent anti-gibberellin. It functions by inhibiting the oxidation of ent-kaurene to ent-kaurenoic acid, a critical early step in the gibberellin biosynthetic pathway. By reducing endogenous levels of active gibberellins, paclobutrazol effectively limits internode elongation, resulting in more compact plant architecture and enhanced resistance to environmental stress.

10. (B) Incomplete, as many hormones function locally near their synthesis site.
The classical definition of hormones required transport from a site of synthesis to a distant target tissue. However, modern plant physiology recognizes that many phytohormones often function locally through paracrine or autocrine mechanisms. Compounds like cytokinins and jasmonates can exert their physiological effects within the same tissue where they are produced, making the strictly long-distance transport model incomplete.

11. (A) Tobacco pith callus bioassay
The tobacco pith callus bioassay is the traditional physiological test used to detect and quantify cytokinins. In this method, tobacco pith tissue is grown on a nutrient medium with a fixed concentration of auxin. The addition of cytokinin induces cell division and callus growth in a dose-dependent manner. This specific interaction between auxin and cytokinin remains a fundamental principle.

12. (C) Auxin
The Avena coleoptile curvature test is a classic bioassay developed to measure auxin activity. When an agar block containing auxin is placed asymmetrically on a decapitated oat coleoptile, the auxin diffuses down one side and stimulates differential elongation. This results in a measurable curvature that is directly proportional to the concentration of auxin present in the agar block.

13. (D) Barley
The standard bioassay for gibberellins utilizes the barley endosperm system. In this assay, gibberellins induce the synthesis and secretion of alpha-amylase from the aleurone layer in embryoless half-seeds. The enzyme then hydrolyzes starch into reducing sugars, and the amount of sugar produced is directly proportional to the concentration of gibberellin applied. This test is highly sensitive and specific.

14. (C) It typically measures the elongation of intact coleoptiles.
Bioassays for abscisic acid focus on its inhibitory effects rather than growth promotion. Common methods include measuring the induction of stomatal closure in epidermal peels or the inhibition of seed germination and seedling growth. Measuring the elongation of intact coleoptiles is a test for growth-promoting hormones like auxins or gibberellins, whereas abscisic acid is a known potent inhibitor of such expansion.

15. (A) Both A and R are true and R is the correct explanation of A.
The triple response is a highly specific phenotype induced by ethylene in dark-grown seedlings. This response includes the inhibition of hypocotyl elongation, radial swelling of the stem, and an exaggerated apical hook. Because this characteristic morphological change is so distinct and dose-dependent, it serves as a reliable and standard bioassay for the presence and activity of ethylene in plants.

16. (D) Bioassays exhibit cross-reactivity and lower absolute quantitative precision.
While physiological bioassays are valuable for detecting biological activity, they lack the precision of modern analytical techniques like GC-MS. Bioassays often suffer from cross-reactivity with other substances and are sensitive to environmental fluctuations during the testing period. Consequently, they provide less accurate quantitative data and are generally slower and more labor-intensive compared to high-resolution chemical quantification methods used today.

17. (A) Gibberellins
The lettuce or cucumber hypocotyl elongation test is a classical bioassay for gibberellins. These hormones specifically promote the expansion of hypocotyl cells in light-grown seedlings. When applied exogenously, gibberellins overcome the inhibitory effect of light on stem elongation. The degree of elongation is measured and used to determine the concentration of bioactive gibberellins present in the sample being tested.

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of active forms like GA1 to inactive forms like GA8 is a common way to assess the hormonal status of plant tissues.

55. (B) Plastid → Endoplasmic Reticulum → Cytosol
Gibberellin biosynthesis is a complex process spanning three distinct cellular compartments. The pathway begins in the plastid with the formation of ent-kaurene. The intermediate then moves to the endoplasmic reticulum, where it is oxidized to GA12. Finally, the conversion into bioactive gibberellins like GA1 or GA4 occurs in the cytosol, catalyzed by soluble 2-oxoglutarate-dependent dioxygenases such as GA 20-oxidase and GA 3-oxidase.

56. (A) GA 2-oxidase
The levels of bioactive gibberellins are tightly controlled by both synthesis and degradation. The GA 2-oxidase enzyme is responsible for the irreversible deactivation of active hormones by catalyzing the addition of a hydroxyl group at the C-2 position. This reaction converts active forms into inactive metabolites. Overexpression of GA 2-oxidase genes typically leads to extreme dwarfism due to the deficiency of bioactive gibberellins.

57. (B) ent-copalyl diphosphate synthase
The first committed step in gibberellin biosynthesis is the cyclization of the 20-carbon precursor geranylgeranyl diphosphate to form ent-copalyl diphosphate. This reaction is catalyzed by the enzyme ent-copalyl diphosphate synthase. This enzyme is a major target for both genetic regulation and synthetic growth retardants, making it a critical control point for determining the overall rate of gibberellin production in the plant.

58. (B) GAs can move strictly via polar transport identical to that of auxins.
Gibberellins move through the plant primarily via the vascular system, including both the xylem and phloem. Unlike auxins, which exhibit a unique and strictly polar transport mechanism mediated by localized carriers, gibberellins are transported non-polarly following the flow of water and photoassimilates. This allows gibberellins to act as long-distance signals that coordinate growth between different organs such as roots and shoots.

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59. (A) ent-copalyl diphosphate synthase
Chlormequat, commonly known as CCC, is a synthetic growth retardant that inhibits the early stages of gibberellin biosynthesis. Specifically, it blocks the enzyme ent-copalyl diphosphate synthase, preventing the cyclization of geranylgeranyl diphosphate. By reducing the pool of precursors available for hormone production, Chlormequat effectively lowers endogenous gibberellin levels, resulting in shorter and sturdier stems in crops like wheat.

60. (C) Common precursor for gibberellins, carotenoids, and phytol.
Geranylgeranyl diphosphate is a central 20-carbon intermediate in the isoprenoid biosynthetic pathway. It is synthesized within the plastid via the MEP pathway and serves as the universal precursor for several essential compounds, including gibberellins, carotenoid pigments, and the phytol side chain of chlorophyll. Because it sits at a major metabolic branch point, its availability is a key factor regulating these different pathways.

61. (D) GID1
GID1 is the primary soluble receptor responsible for perceiving bioactive gibberellins in the nucleus. When a gibberellin molecule binds to the GID1 receptor, it induces a conformational change that allows the receptor to interact with DELLA repressor proteins. This interaction is the first step in the signaling cascade that ultimately leads to the degradation of the repressors and the activation of growth.

62. (C) Transcriptional repressors of GA-induced gene expression
DELLA proteins are nuclear-localized proteins that function as powerful negative regulators of the gibberellin signaling pathway. They act as repressors by binding to and inhibiting various transcription factors that would otherwise activate GA-responsive genes. In the absence of the hormone, DELLA proteins accumulate and suppress growth. The primary role of gibberellin is to trigger the degradation of these DELLA proteins to allow growth to proceed.

63. (B) SLY1
SLY1 is an F-box protein in Arabidopsis that is essential for the gibberellin response. It acts as the substrate recognition component of an SCF E3 ubiquitin ligase complex. Once the GID1

81. (A) Two-component phosphorelay system
Cytokinin signaling in plants is remarkably similar to the two-component systems used by bacteria to sense environmental changes. It involves a multi-step phosphorelay starting with a membrane-bound receptor. When cytokinin binds, the receptor autophosphorylates and transfers the phosphate group to an intermediary phosphotransfer protein. This protein then moves into the nucleus to activate response regulators, which serve as transcription factors for cytokinin-responsive genes.

82. (C) Membrane-localized sensor histidine kinases
The primary cytokinin receptors, such as CRE1/AHK4, are located on cellular membranes, particularly the endoplasmic reticulum and plasma membrane. They are structurally classified as sensor histidine kinases. These receptors have an extracellular or lumenal CHASE domain that binds the cytokinin molecule. This binding triggers the kinase activity of the receptor, initiating the phosphorelay cascade that carries the signal to the nucleus.

83. (A) Arabidopsis Histidine Phosphotransfer (AHP) proteins
Upon perception of cytokinin, the activated receptor transfers a phosphate group to a specific class of cytosolic proteins known as AHPs. These proteins serve as mobile signal carriers that shuttle between the cytoplasm and the nucleus. The phosphorylation of AHPs is a critical intermediary step that allows the hormonal signal to be transmitted from the membrane-bound receptors to the nuclear-localized transcription factors.

84. (D) Type-B ARRs
Type-B ARRs are the primary transcription factors that function as positive regulators of the cytokinin response. When they receive a phosphate group from AHP proteins, they bind to specific DNA sequences in the promoters of cytokinin-responsive genes. This leads to the activation of transcription for various targets, including Type-A ARRs and genes involved in cell division. They are essential for initiating the cellular changes induced by cytokinins.

85. (A) Both A and R are true and R is the correct explanation of A.
Cytokinins play a vital role in regulating the cell cycle, particularly during the transition from the G1 phase to the S phase. They achieve this by inducing the expression of D-type cyclins, such as CycD3. These cyclins then activate cyclin-dependent kinases that are necessary for DNA replication. This molecular link explains why cytokinins are absolutely required for cell division and organogenesis in plant tissues.

86. (C) Richmond-Lang effect
The Richmond-Lang effect refers to the ability of cytokinins to delay the senescence of detached leaves. Localized application of the hormone prevents the breakdown of chlorophyll and proteins, creating a "green island" of healthy tissue. This effect is due to the hormone's role in stabilizing chloroplasts and promoting the mobilization of nutrients toward the treated area, effectively extending the lifespan of the leaf.

87. (D) CRE1 – Soluble nuclear receptor
The CRE1 protein, also known as AHK4, is a membrane-localized sensor histidine kinase, not a soluble nuclear receptor. It is primarily found on the endoplasmic reticulum membrane where it perceives cytokinin. The other pairs are correct: AHPs are phosphotransfer proteins, Type-A ARRs function as negative feedback regulators, and Type-B ARRs are the positive transcription factors that activate the primary cytokinin response.

88. (A) They lack a DNA-binding domain and act as negative regulators.
Type-A ARRs are structurally distinct from Type-B ARRs because they lack the C-terminal DNA-binding domain required for transcription. Instead, they consist mainly of a receiver domain that can be phosphorylated. Their primary function is to act as negative feedback inhibitors of the cytokinin signaling pathway. By competing for phosphate groups from AHP proteins, they help to fine-tune and attenuate the overall hormonal response.

89. (B) Decreased shoot growth and enhanced root elongation.
Type-B ARRs are positive regulators of shoot growth. If their function is blocked by a dominant-negative form, the plant will show reduced sensitivity to cytokinin, leading to a smaller shoot apical meristem and decreased shoot growth. Interestingly, because cytokinin and auxin act antagonistically in the roots, a reduction in cytokinin signaling often results in

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of an adenine nucleotide, such as ATP or ADP. This rate-limiting step is catalyzed by the enzyme isopentenyl transferase. The resulting isopentenyladenine nucleotides are then further modified into various active cytokinin forms. This pathway ensures that cytokinin production is closely linked to cellular energy status and isoprenoid metabolism.

73. (B) Root apical meristem
While many plant tissues have the capacity to synthesize cytokinins, the root apical meristem is widely considered the primary site of major production in a mature plant. Cytokinins produced in the roots are subsequently transported through the xylem to the shoot system, where they regulate leaf expansion, delay senescence, and antagonize apical dominance. This root-to-shoot signaling is essential for coordinating the growth of different plant organs.

74. (B) Thidiazuron
trans-Zeatin, cis-zeatin, and isopentenyladenine are all naturally occurring cytokinins found in various plant species. Thidiazuron, however, is a synthetic compound that exhibits potent cytokinin-like activity but is not produced by plants naturally. It is frequently used in plant tissue culture to induce shoot regeneration and in agriculture as a defoliant. Its high activity stems from its ability to inhibit the cytokinin oxidase enzyme.

75. (A) I - II - III - IV
Cytokinin metabolism follows a specific sequence. First, isopentenyl transferase attaches DMAPP to ATP or ADP. This forms isopentenyladenine nucleotides, which are then hydroxylated by cytochrome P450 enzymes to produce zeatin-type nucleotides. Finally, active cytokinins can be irreversibly degraded by cytokinin oxidase, which removes the side chain. This sequence of synthesis, modification, and degradation allows the plant to maintain precise control over active cytokinin levels.

76. (C) Zeatin O-glucoside
Plants can regulate active cytokinin levels through reversible conjugation. Zeatin O-glucoside is a common storage form created by adding a glucose molecule to the hydroxyl group of the side chain. These O-glucosides are inactive but can be rapidly hydrolyzed back into free, active zeatin by beta-glucosidase enzymes when needed. This mechanism provides a flexible way for the plant to store and mobilize hormone reserves.

77. (D) N6-isoprenoid side chain from the adenine ring
Cytokinin oxidase, also known as cytokinin dehydrogenase, is the primary enzyme responsible for the irreversible degradation of cytokinins. It works by specifically cleaving the unsaturated N6-isoprenoid side chain from the adenine ring. This reaction produces adenine and an aldehyde, neither of which has cytokinin activity. By regulating the expression of CKX genes, plants can effectively lower cytokinin concentrations to control growth and development.

78. (C) Xylem transpiration stream
The majority of cytokinins synthesized in the roots are transported to the aerial parts of the plant through the xylem. They move as ribosides or nucleotides within the transpiration stream. Once they reach the leaves and shoot meristems, they are converted into active forms to regulate processes such as cell division and the delay of senescence. This long-distance transport is a key mechanism for root-shoot communication.

79. (B) It exhibits higher biological activity than trans-zeatin.
trans-Zeatin and cis-zeatin are isomers that differ in the geometry of their side chains. In most higher plants, trans-zeatin is the predominant and much more biologically active form. While cis-zeatin is abundant in certain species like rice and maize and is primarily derived from tRNA degradation, it generally possesses much lower affinity for cytokinin receptors and lower overall biological activity compared to the trans isomer.

80. (D) Cytokinin
Agrobacterium tumefaciens genetically transforms plant cells by transferring T-DNA into their genome. This T-DNA contains the tmr gene, which encodes an isopentenyl transferase enzyme. This enzyme drives the overproduction of cytokinins within the transformed cells. Combined with the simultaneous overproduction of auxin, this hormonal imbalance leads to uncontrolled cell division and the characteristic formation of crown gall tumors on the host plant.

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receptors are not located in the nucleus. Instead, they are perceived by the plasma membrane-localized receptor kinase BRI1. Upon hormone binding, BRI1 interacts with its co-receptor BAK1 to initiate a phosphorylation cascade. This ultimately leads to the dephosphorylation and stabilization of transcription factors like BES1 and BZR1, which then regulate gene expression.

28. (C) JAZ proteins
In the jasmonate signaling pathway, the active hormone jasmonoyl-isoleucine facilitates the binding of the SCF-COI1 ubiquitin ligase to JAZ repressor proteins. This interaction leads to the ubiquitination and subsequent degradation of JAZ proteins by the 26S proteasome. The removal of these repressors releases transcription factors like MYC2, allowing for the activation of jasmonate-responsive genes involved in defense and various developmental processes.

29. (D) Chorismate and Phenylalanine
Salicylic acid biosynthesis in plants occurs through two primary biochemical routes. One pathway utilizes phenylalanine as a precursor and involves the enzyme phenylalanine ammonia-lyase. The second, and often more dominant pathway under stress conditions, proceeds directly from chorismate via the enzyme isochorismate synthase. Both pathways are essential for the production of this critical defense hormone and the establishment of systemic resistance.

30. (C) Enhanced tillering and shoot branching
The D14 protein serves as the primary receptor for strigolactones, which are known inhibitors of shoot branching. A mutation in the D14 gene prevents the plant from perceiving strigolactone signals, leading to the loss of growth suppression in axillary buds. As a result, mutant plants exhibit a highly branched or tillered phenotype. This demonstrates the hormone's critical role in maintaining apical dominance.

31. (B) Indole-3-pyruvic acid (IPA)
The most prevalent tryptophan-dependent pathway for auxin biosynthesis involves indole-3-pyruvic acid as a key intermediate. Tryptophan is first converted to IPA by the TAA1 family of aminotransferases. Subsequently, IPA is converted to indole-3-acetic acid by YUCCA flavin monooxygenases. This two-step pathway is considered the main route for maintaining proper auxin levels during most stages of plant growth and development across species.

32. (D) Indole-3-glycerol phosphate
In the tryptophan-independent pathway, auxin is synthesized from precursors within the shikimate pathway without passing through the amino acid tryptophan. The primary intermediate for this route is indole-3-glycerol phosphate. This pathway provides plants with an alternative mechanism to produce indole-3-acetic acid, although it is generally less understood than the tryptophan-dependent routes and may be more prominent during specific developmental stages.

33. (A) PIN-FORMED (PIN) proteins
Polar auxin transport is a directed movement of the hormone from the shoot apex to the roots. This process is primarily mediated by PIN-FORMED efflux carrier proteins, which are asymmetrically localized on the plasma membrane of cells. The specific positioning of these carriers determines the direction of auxin flow, allowing for the establishment of hormone gradients that are essential for morphogenesis.

34. (C) 1-Naphthylphthalamic acid (NPA)
1-Naphthylphthalamic acid is a powerful synthetic inhibitor used to study polar auxin transport. It specifically binds to and inhibits the activity of auxin efflux carriers, particularly the PIN protein family. By blocking the exit of auxin from cells, NPA disrupts the directional flow of the hormone, leading to severe developmental defects such as the loss of gravitropism and altered vascular patterning.

35. (A) P-1, Q-2, R-3, S-4
Auxin homeostasis is regulated by several key components. YUCCA enzymes are flavin monooxygenases that synthesize IAA. AUX1 serves as a high-affinity influx carrier that brings auxin into cells. ABCB proteins are ATP-dependent transporters that facilitate auxin efflux. Finally, GH3 enzymes regulate free auxin levels by conjugating the hormone to various amino acids, which can either store or target it for degradation.

36. (D) The acidic cell wall keeps a portion of IAA protonated (IAAH), which diffuses across the plasma membrane.
The chemiosmotic model explains auxin entry into cells based on pH differences. The relatively

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enhanced root system development and increased root elongation.

90. (B) Shoot organogenesis
In plant tissue culture, the relative concentrations of auxin and cytokinin determine the type of organogenesis. While a high auxin-to-cytokinin ratio promotes root formation, a high cytokinin-to-auxin ratio induces the development of shoots from the callus. This classic Skoog and Miller model demonstrates how the balance between these two hormones coordinates the regeneration of entire plants from undifferentiated tissue masses.

91. (A) 9-cis-epoxycarotenoid dioxygenase (NCED)
The enzyme NCED is the primary regulatory and rate-limiting step in the biosynthesis of abscisic acid. It catalyzes the oxidative cleavage of 9-cis-epoxycarotenoids into xanthoxin. Because this reaction is the first committed step in the pathway and is highly induced by environmental stresses like drought, the expression level of NCED genes directly determines the endogenous concentration of abscisic acid in plant tissues.

92. (C) 9-cis-neoxanthin or 9-cis-violaxanthin
Abscisic acid is synthesized through the indirect carotenoid pathway. The process involves the cleavage of 40-carbon precursor molecules, specifically 9-cis-neoxanthin or 9-cis-violaxanthin. These molecules are cleaved by the enzyme NCED to produce the 15-carbon intermediate xanthoxin. This mechanism links the production of the stress hormone to the abundance of carotenoids in the plastids, providing a robust precursor pool for hormone synthesis.

93. (D) Plastid
The early steps of abscisic acid biosynthesis take place within the plastids. This includes the conversion of zeaxanthin into epoxycarotenoids and their subsequent cleavage by NCED to form xanthoxin. Since carotenoids are abundant in plastids, this localization provides the necessary substrates for hormone production. Xanthoxin then exits the plastid and moves into the cytosol for the final enzymatic steps of the pathway.

94. (C) Phaseic acid
Abscisic acid can be transported throughout the plant in several forms. Free ABA is found in both the xylem and phloem, and ABA-glucose esters serve as a conjugated transport form that can be hydrolyzed to release active hormone. Phaseic acid, however, is a primary catabolic product of ABA degradation. It is generally considered biologically inactive or has very low activity, representing a metabolic sink rather than a transport form.

95. (B) Cytosol
The final two steps of abscisic acid biosynthesis occur in the cytosol. After being produced in the plastid, xanthoxin is transported to the cytosol where it is converted into ABA aldehyde by a short-chain dehydrogenase. Subsequently, ABA aldehyde is oxidized to form bioactive abscisic acid by the enzyme ABA aldehyde oxidase. This compartmentalization allows the plant to separate early synthesis from the final activation steps.

96. (D) Cytochrome P450 monooxygenase
The primary pathway for the irreversible inactivation of abscisic acid involves its hydroxylation at the 8' position. This reaction is catalyzed by the enzyme ABA 8'-hydroxylase, which belongs to the cytochrome P450 monooxygenase family. This enzyme is highly regulated and is rapidly induced when ABA levels need to be lowered, such as during rehydration after drought. The resulting 8'-hydroxy-ABA is then spontaneously converted into inactive phaseic acid.

97. (A) It retains strong ABA-like activity in inducing stomatal closure.
Phaseic acid is the immediate product formed from the rearrangement of 8'-hydroxy-ABA and is a major catabolite of abscisic acid. Unlike its precursor, phaseic acid has significantly reduced biological activity and does not effectively induce stomatal closure or seed dormancy. Its formation represents a critical pathway for the enzymatic deactivation of the hormone, ensuring that ABA signaling is terminated once the stress condition has passed.

98. (C) It is hydrolyzed by beta-glucosidases to release free ABA.
ABA-glucose ester is an inactive, conjugated form of the hormone that can be stored in the vacuole or apoplast. Under sudden osmotic stress, the plant can rapidly increase its free ABA levels by activating beta-glucosidase enzymes. These enzymes hydrolyze the glucose ester, releasing

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or the perception of strigolactones. Their failure leads to the loss of branching inhibition, allowing all axillary buds to grow out simultaneously.

169. (B) Enhanced apical dominance and branching suppression.
Plants grown under a dense canopy perceive a low ratio of red to far-red light, which triggers the shade avoidance response. This response is characterized by an increase in apical dominance and the suppression of axillary bud outgrowth. By prioritizing vertical growth over branching, the plant attempts to reach higher light levels above the canopy. This strategy is mediated by changes in the levels and sensitivity to auxin and strigolactones.

170. (B) Increased root-derived cytokinins and decreased strigolactone exudation.
Nutrient availability, particularly nitrogen and phosphorus, significantly influences shoot branching. High nitrogen levels promote branching by increasing the synthesis of cytokinins in the roots and their transport to the shoot. Simultaneously, high nutrient levels lead to a decrease in the production and exudation of strigolactones. This dual hormonal change creates an environment that favors the outgrowth of axillary buds and tillers, maximizing the plant's light-capturing capacity.

171. (A) FLOWERING LOCUS T (FT) protein.
For many years, the identity of the mobile "florigen" signal remained a mystery. It is now known that the FT protein is synthesized in the leaves in response to favorable photoperiodic conditions. This protein then travels through the phloem to the shoot apical meristem. Once there, it interacts with other transcription factors to initiate the transition from vegetative growth to reproductive development, triggering the formation of flowers.

172. (C) Gibberellin
In many rosette plants, the transition to flowering is accompanied by a rapid elongation of the stem, known as bolting. This process is naturally triggered by long days or cold temperatures. However, the exogenous application of gibberellins can bypass these environmental requirements and induce bolting and flowering even under non-inductive conditions. This demonstrates that gibberellins are the primary endogenous signals that coordinate stem expansion and floral initiation in these species.

173. (D) Female flowers
In cucurbits like cucumbers, ethylene is a powerful regulator of sex expression. High levels of ethylene, often achieved through the application of ethephon, promote the development of female flowers (pistillate) over male flowers (staminate). This effect is used commercially to increase the number of fruit-bearing flowers per plant, thereby improving yield. The ability of ethylene to determine floral sex highlights its role as a fundamental developmental signal.

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174. (C) Auxins and Gibberellins
Parthenocarpy is the production of fruit without the need for pollination or fertilization. This process can be artificially induced by treating unpollinated ovaries with auxins or gibberellins. These hormones mimic the signals naturally produced by developing seeds, triggering the division and expansion of the ovary tissues. This technique is commonly used to produce seedless varieties of horticultural crops like tomatoes, grapes, and citrus.

175. (C) A is true but R is false.
In several dioecious plant species, the application of gibberellins promotes the development of male flowers. This is seen in plants like spinach and hemp. However, the reason provided is incorrect because the effect of gibberellins on sex expression is highly species-dependent. While they promote maleness in some plants, they can have the opposite effect in others. Phytohormone effects are often context-specific and vary across different plant families.

176. (D) FLOWERING LOCUS C (FLC).
Vernalization is the process where flowering is promoted by a prolonged period of cold. In Arabidopsis, the central regulator of this response is FLC, a transcription factor that acts as a powerful repressor of flowering. Cold exposure leads to the stable, epigenetic silencing of the FLC gene. Once FLC levels drop, the repression on floral integrators like FT is removed, allowing the plant to flower when warmer temperatures return.

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channels and the plasma membrane H^+-ATPase. By blocking these components, calcium prevents the uptake of solutes and the establishment of the proton gradient required for stomatal opening. This ensures that the stomata remain tightly closed to conserve water during stress.

108. (C) Auxin influx carrier AUX1
Stomatal closure involves a complex signaling network that includes the production of reactive oxygen species and nitric oxide. NADPH oxidases on the plasma membrane generate a burst of hydrogen peroxide, which acts as a signaling molecule to open calcium channels. While these components are essential for the ABA response, the auxin influx carrier AUX1 is not positively associated with this pathway and functions primarily in auxin transport.

109. (D) Constitutive ABA responses, hyper-dormant seeds, and closed stomata.
PP2C phosphatases are essential negative regulators that keep the ABA signaling pathway inactive. If a mutant lacks these phosphatases, the SnRK2 kinases remain constitutively active even without the hormone. This leads to a permanent state of ABA response, where the plant acts as if it is under constant drought stress. Such mutants typically exhibit extremely closed stomata and seeds that are hyper-dormant and difficult to germinate.

110. (C) The receptor inhibits a repressor (PP2C), releasing a kinase (SnRK2).
The "double negative" regulatory system of ABA signaling refers to the two consecutive inhibitory steps. First, the ABA receptor binds to and inhibits the PP2C phosphatase, which is itself a negative regulator. This inhibition then releases the SnRK2 kinase from the phosphatase's suppression. This mechanism allows for a rapid and sensitive response to the hormone, as the signaling components are pre-assembled and ready to be activated.

111. (B) Recycles the methylthio group of SAM, maintaining the methionine pool.
The Yang Cycle, also known as the methionine salvage pathway, is vital for sustained ethylene production. During the synthesis of ACC from SAM, a byproduct called methylthioadenosine is formed. The Yang Cycle recycles the methylthio group of this byproduct back into methionine. This recycling ensures that the plant does not deplete its limited pool of methionine, allowing for continuous ethylene synthesis during prolonged processes like fruit ripening.

112. (D) ACC synthase (ACS)
The enzyme ACC synthase catalyzes the conversion of S-adenosylmethionine to 1-aminocyclopropane-1-carboxylic acid. This reaction is the primary rate-limiting and highly regulated step in the ethylene biosynthetic pathway. Various environmental and internal signals, such as wounding or fruit ripening, lead to the rapid transcriptional and post-translational upregulation of ACS, which then triggers a massive increase in ethylene production.

113. (A) Oxygen (O_2) and ascorbate
The final step of ethylene biosynthesis is the conversion of ACC to ethylene, catalyzed by the enzyme ACC oxidase. This enzymatic reaction is strictly dependent on the presence of molecular oxygen and uses ascorbate as a reducing agent. Because of this oxygen requirement, ethylene production is severely limited under anaerobic or hypoxic conditions, such as during soil flooding, regardless of the amount of ACC precursor available.

114. (C) Continuous red light irradiation.
Ethylene production is typically induced by various forms of biotic and abiotic stress. Flooding, mechanical wounding, and pathogen attacks all lead to a rapid increase in ACS activity and an ethylene burst. However, continuous red light irradiation generally suppresses ethylene production in many plant tissues. This suppression is part of the light-mediated regulation of growth and helps etiolated seedlings transition to a normal vegetative growth pattern.

115. (C) Methionine → SAM → ACC → Ethylene
The ethylene biosynthetic pathway follows a well-defined sequence starting from the amino acid methionine. Methionine is first converted to S-adenosylmethionine by SAM synthetase. SAM is then converted to 1-aminocyclopropane-1-carboxylic acid by the enzyme ACC synthase. Finally, ACC is oxidized to gaseous ethylene by ACC oxidase. This pathway, identified by Shang Fa Yang, is universal across all higher plant species studied to date.

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116. (D) Polyamines
S-adenosylmethionine is a central metabolic intermediate that serves as a precursor for both ethylene and polyamines. While the majority of SAM is used for transmethylation reactions, it can be diverted toward ethylene synthesis via ACC or toward polyamine synthesis via decarboxylated SAM. This shared precursor link means that there is potential metabolic competition and crosstalk between these two important growth-regulating pathways.

117. (B) Phosphorylation by kinases like MPK6, preventing degradation.
The activity of the ACC synthase enzyme is tightly regulated at the post-translational level. Specific kinases, such as MPK6, can phosphorylate the C-terminal domain of ACS proteins. This phosphorylation increases the stability of the enzyme by preventing its recognition and degradation by the E3 ubiquitin ligase machinery. This stabilization allows for the rapid accumulation of the enzyme and a subsequent surge in ethylene production during stress responses.

118. (C) ACC oxidase requires oxygen, which is deficient in floods.
In waterlogged or flooded soils, the root system experience severe hypoxia due to the slow diffusion of oxygen in water. While the synthesis of the ethylene precursor ACC can continue under these conditions, its conversion to ethylene is blocked because the enzyme ACC oxidase requires molecular oxygen for its catalytic activity. This results in the accumulation of ACC in the roots, which is then transported to the shoot.

119. (D) Ethylene is actively transported long distances via specialized carrier proteins in the phloem.
Unlike other plant hormones, ethylene is a small gaseous molecule that diffuses easily through cellular membranes and air spaces. It does not require specialized carrier proteins for long-distance transport. Instead, it can move from its site of synthesis to other parts of the plant through simple diffusion. Alternatively, its precursor ACC can be transported through the vascular system, primarily the xylem, to distant tissues where it is then converted.

120. (A) Cyanide (HCN)
The conversion of ACC to ethylene by ACC oxidase produces two additional byproducts: carbon dioxide and cyanide. While cyanide is a potent toxin, plant cells possess a highly active detoxification enzyme called beta-cyanoalanine synthase. This enzyme rapidly converts the cyanide into non-toxic amino acids. This efficient detoxification pathway allows plants to produce large amounts of ethylene during ripening or stress without suffering from cyanide poisoning.

121. (B) Endoplasmic reticulum membrane
Ethylene receptors, such as ETR1, are unique because they are localized primarily to the membranes of the endoplasmic reticulum rather than the plasma membrane. This internal localization means that the gaseous hormone must diffuse into the cell to be perceived. The receptors are integrated into the ER membrane with their ethylene-binding domains facing the lumen or the membrane interior, where they coordinate the downstream signaling cascade.

122. (B) Copper (Cu^{+})
The binding of ethylene to its receptors is strictly dependent on the presence of a copper cofactor. Each receptor dimer contains a single copper ion coordinated within its hydrophobic binding pocket. This copper ion is essential for the high-affinity interaction between the gaseous hormone and the protein. Without copper, the receptors are unable to perceive ethylene, which explains why copper deficiency can significantly disrupt ethylene-mediated responses in plants.

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123. (A) A negative regulator that represses signaling in ethylene's absence.
CTR1 is a serine/threonine protein kinase that acts as a central negative regulator of the ethylene signaling pathway. In the absence of the hormone, ethylene receptors are in an active state and directly bind to and activate CTR1. The active CTR1 then phosphorylates the downstream protein EIN2, keeping it inactive and preventing the signal from reaching the nucleus. Ethylene binding deactivates the receptors, thereby turning off CTR1.

124. (C) EIN2
EIN2 is a critical transmembrane protein located in the endoplasmic reticulum that acts as a positive regulator of ethylene signaling. In the absence of ethylene, it is kept inactive by

phosphorylation. When ethylene is perceived, the suppression is lifted, and EIN2 undergoes a specific proteolytic cleavage. The released C-terminal fragment then translocates into the nucleus, where it stabilizes transcription factors to initiate the hormonal response.

125. (D) I, II and III
The transcriptional regulation of ethylene responses involves the stabilization of primary transcription factors, EIN3 and EIL1. In the absence of the hormone, these proteins are constantly targeted for degradation by the EBF1 and EBF2 F-box proteins. Perception of ethylene leads to the degradation of these F-box proteins, allowing EIN3 to accumulate in the nucleus. Once stabilized, EIN3 activates the expression of numerous downstream ethylene-responsive genes.

126. (C) Enhanced proliferation of lateral roots
The classic "triple response" of etiolated dicot seedlings to ethylene consists of three distinct morphological changes. These are the inhibition of hypocotyl and root elongation, the radial swelling of the hypocotyl, and the development of an exaggerated apical hook. This response helps the seedling navigate through soil obstacles during emergence. Enhanced proliferation of lateral roots is not part of this specific, rapid morphological response to ethylene.

127. (B) Active in ethylene's absence, activating CTR1 to repress the pathway.
Ethylene receptors operate through a unique mechanism where they are active in the absence of their ligand. In this air-grown state, the receptors activate the negative regulator CTR1, which suppresses the signaling pathway. When ethylene binds to the receptors, it turns them off, which in turn deactivates CTR1. This "releasing" mechanism means that the ethylene response is triggered by the removal of a constitutive repression.

128. (D) Photosynthetic light-harvesting complex genes
ERF1 is a key secondary transcription factor that coordinates a wide range of ethylene-mediated responses. It activates genes involved in leaf abscission, fruit ripening, and defense against pathogens. However, it does not typically target genes for the photosynthetic light-harvesting complex. In fact, ethylene signaling often leads to the downregulation of photosynthetic activity and the degradation of chlorophyll during processes like senescence and fruit ripening.

129. (A) Insensitive to ethylene, failing to show the triple response.
In the ethylene signaling pathway, the receptors are active in the absence of the hormone and act as negative regulators. A dominant mutation in ETR1 that prevents ethylene from binding will lock the receptor in its "active" state forever. Consequently, the receptor will continue to suppress the signaling pathway regardless of the presence of ethylene gas. This results in a plant that is completely insensitive to the hormone.

130. (C) Constitutive triple response
CTR1 is a negative regulator that suppresses the ethylene signaling pathway. If the CTR1 gene is lost due to a mutation, the repression is removed, and the signaling pathway remains "on" all the time. As a result, the plant will display all the characteristics of the ethylene response, such as the triple response in etiolated seedlings, even when grown in the complete absence of ethylene gas.

131. (A) Auxin
The TIR1 protein is the primary nuclear receptor for auxin. It functions as an F-box protein that targets Aux/IAA repressor proteins for degradation in the presence of the hormone. Consequently, the tir1 mutant in Arabidopsis exhibits a significant loss of sensitivity to auxin, leading to defects in various auxin-mediated processes such as root growth, lateral root formation, and gravitropism.

132. (D) ent-copalyl diphosphate synthase
The ga1 mutant of Arabidopsis is a classic example of a gibberellin-deficient plant. The GA1 gene encodes ent-copalyl diphosphate synthase, which catalyzes the first committed step in the gibberellin biosynthetic pathway. Because this mutant cannot produce its own gibberellins, it exhibits severe dwarfism and a failure to germinate. These phenotypes can be completely rescued by the exogenous application of bioactive gibberellins like GA3.

133. (B) etr1-1 is ethylene-insensitive, while ctr1 is a constitutive ethylene responder.
The etr1-1 mutation is a dominant change that prevents ethylene from binding to the receptor,

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active abscisic acid. This mechanism allows for a faster response than de novo synthesis, providing an immediate defense against water loss.

99. (A) De novo synthesis from transcriptional upregulation of NCED genes.
When plants experience soil drying, the massive increase in endogenous abscisic acid is primarily driven by the de novo synthesis of the hormone. This is achieved through the rapid transcriptional upregulation of genes encoding the NCED enzyme, which is the rate-limiting step in the pathway. This transcriptional response is highly sensitive to changes in leaf water potential, allowing for precise control of ABA-mediated drought tolerance.

100. (D) (+)-S-enantiomer of cis-trans ABA is the natural active form.
The biological activity of abscisic acid is highly dependent on its specific chemical structure. The natural, bioactive form is the (+)-S-enantiomer with a cis-trans configuration of the side chain. While other isomers can be synthesized chemically, they often show much lower or no activity in physiological assays. This structural specificity ensures that the hormone interacts correctly with its receptors to trigger the appropriate cellular responses.

101. (B) PYR/PYL/RCAR proteins
The PYR/PYL/RCAR proteins are a large family of soluble cytosolic and nuclear receptors that serve as the primary sensors for abscisic acid. They are characterized by a START domain that forms a binding pocket for the hormone. Upon binding ABA, these receptors undergo a conformational change that allows them to interact with and inhibit PP2C phosphatases, which is the first step in the signaling cascade.

102. (C) Negative regulators that dephosphorylate and inhibit SnRK2s.
In the absence of abscisic acid, PP2C phosphatases act as powerful negative regulators of the signaling pathway. They bind directly to SnRK2 kinases and keep them inactive by dephosphorylating their activation loop. This prevents the kinases from phosphorylating downstream targets like ion channels and transcription factors. By keeping the pathway "off" in the absence of stress, the plant avoids the growth-inhibiting effects of ABA.

103. (D) PP2C
When abscisic acid binds to the PYR/PYL/RCAR receptor, it induces the closure of a molecular "lid" over the binding pocket. This creates a surface that can bind to and inhibit the activity of Type 2C protein phosphatases. This inhibition is the central event in ABA perception, as it prevents the PP2Cs from keeping the SnRK2 kinases inactive. This releasing mechanism allows the signal to proceed.

104. (A) Influx of potassium ions (K^+) through inward-rectifying channels
ABA-induced stomatal closure is achieved by reducing the turgor pressure of guard cells. This process involves the efflux of anions and potassium ions, which leads to water leaving the cells. Inward-rectifying potassium channels, which are responsible for potassium uptake and stomatal opening, are specifically inhibited during this process. Therefore, the influx of potassium ions is eliminated to ensure that the stomata remain closed during drought stress.

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105. (A) P-2, Q-3, R-4, S-1
The ABA signaling pathway in guard cells involves several coordinated components. PYR/PYL serves as the receptor. SnRK2 is the kinase that activates downstream targets. SLAC1 is a slow-type anion channel that mediates the efflux of chloride and malate, leading to depolarization. Finally, KAT1 is an inward-rectifying potassium channel that is inhibited by the signaling cascade to prevent re-opening and ensure efficient stomatal closure.

106. (B) Depolarization of the guard cell plasma membrane
The activation of SLAC1 anion channels by SnRK2 kinases allows negatively charged ions like chloride and malate to exit the guard cell. This efflux of anions leads to a significant depolarization of the plasma membrane. This depolarization then activates outward-rectifying potassium channels, allowing potassium to leave the cell as well. The net loss of solutes reduces turgor pressure, causing the stomata to close.

107. (A) Inward-rectifying K^+ channels and plasma membrane H^+-ATPases.
Increased cytosolic calcium levels play a central role in the ABA signaling pathway in guard cells. Calcium ions act as second messengers that inhibit both inward-rectifying potassium

142. (C) Upregulating GA 3-oxidase and downregulating GA 2-oxidase.
Auxin and gibberellin act synergistically to promote stem elongation. One way auxin achieves this is by regulating gibberellin metabolism. Auxin promotes the expression of GA 3-oxidase, the enzyme that produces bioactive gibberellins, while simultaneously suppressing the expression of GA 2-oxidase, which inactivates them. This coordination ensures that high auxin levels lead to an increase in active gibberellins, resulting in a more pronounced growth response.

143. (B) ABA : GA
The transition between seed dormancy and germination is primarily controlled by the antagonistic balance between abscisic acid and gibberellins. ABA is the primary hormone that induces and maintains dormancy during seed maturation. In contrast, GAs are essential for breaking dormancy and initiating the germination process by stimulating embryo growth and nutrient mobilization. The ratio of these two hormones acts as a developmental switch for the seed.

144. (D) Phototropic curvature of coleoptiles
While auxin and ethylene exhibit significant crosstalk in many processes like leaf abscission, apical hook formation, and lateral root emergence, they do not typically show antagonistic interactions during phototropism. Phototropic curvature is primarily driven by the lateral redistribution of auxin in response to light, leading to differential growth. This specific response is largely independent of ethylene signaling, which more commonly regulates growth rate and stress-related morphological changes.

145. (C) III only
The regulation of shoot branching involves complex interactions. Auxin produced in the apex travels down the stem and upregulates strigolactone biosynthesis. Strigolactones then act as negative regulators by inhibiting axillary bud outgrowth. They also influence auxin transport by downregulating PIN carriers. Statement III is incorrect because auxin does not enter the axillary bud directly to activate strigolactone receptors; its inhibitory effect is mediated indirectly through strigolactones and cytokinins.

146. (C) Joint effect is greater than the sum of individual effects.
In plant physiology, synergism occurs when two hormones interact in such a way that their combined effect is significantly greater than the sum of their individual effects. This often happens because one hormone sensitizes the tissue to the other or regulates its biosynthesis or signaling components. Synergistic interactions allow plants to achieve massive physiological responses through the coordinated action of multiple signaling pathways.

147. (A) Auxin promotes division in the meristem, while cytokinin promotes differentiation.
The root apical meristem is a site of intense hormonal crosstalk between auxin and cytokinin. Auxin is essential for maintaining cell division in the meristematic zone. In contrast, cytokinins act at the transition zone to promote the exit of cells from the mitotic cycle and initiate their differentiation. This balance between division and differentiation is critical for maintaining the proper size and function of the root tip.

148. (D) Salicylic acid (SA) and Jasmonic acid (JA).
Plants use different hormonal pathways to defend against different types of pathogens. Salicylic acid signaling is primarily effective against biotrophic pathogens that feed on living tissue. Conversely, jasmonic acid and ethylene signaling are required for defense against necrotrophic pathogens that kill host cells. These two pathways are typically antagonistic, meaning that the activation of one can suppress the other, allowing the plant to prioritize its defense strategy.

149. (B) Unorganized cell division (callus formation).
When plant tissues are grown in culture with approximately equal concentrations of both auxin and cytokinin, they typically undergo rapid but unorganized cell division. This results in the formation of a callus, which is a mass of undifferentiated parenchyma cells. This phenomenon demonstrates that while both hormones are required for the cell cycle, it is the specific ratio between them that provides the positional information necessary for organogenesis.

150. (C) ABA
Glucose acts as a signaling molecule in plants and can significantly influence development. High concentrations of exogenous glucose can inhibit

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locking it in an "on" state that suppresses signaling. This makes the plant insensitive to ethylene. In contrast, ctr1 is a loss-of-function mutation in a negative regulator. Without CTR1 to suppress the pathway, the signaling remains active constantly, leading to a constitutive ethylene response even in the absence of the hormone.

134. (C) ein2 (ethylene signaling mutant)
Precocious germination and reduced seed dormancy are typically associated with defects in abscisic acid synthesis or signaling. Mutants like aba1, nced3, and abi3 fail to establish or maintain dormancy, leading to vivipary. While ethylene is involved in various aspects of seed physiology, an ein2 mutant, which is defective in ethylene signaling, would not be expected to show a severe vivipary phenotype as it does not directly control ABA-mediated dormancy.

135. (C) A is true but R is false.
The sleepy1 mutant in Arabidopsis is severely dwarfed because it cannot respond to gibberellins. SLY1 encodes an F-box protein that is responsible for targeting DELLA repressor proteins for degradation. In the absence of SLY1, DELLA proteins accumulate to very high levels, constantly repressing growth. While the mutant is GA-insensitive, the reason is the failure to degrade repressors, not a defect in the GID1 receptor itself.

136. (A) Displays the hormone phenotype even in the hormone's absence.
A "constitutive response" mutant is one where the signaling pathway for a particular hormone is permanently activated, regardless of whether the hormone is actually present. This usually occurs due to a loss-of-function mutation in a negative regulator or a gain-of-function mutation in a positive regulator. Such mutants are valuable tools for identifying the components and the logic of hormonal signaling cascades in plants.

137. (B) cre1 – Cytokinin insensitivity and reduced shoot growth.
The cre1 mutant in Arabidopsis is defective in one of the primary cytokinin receptors. Since cytokinins are essential for cell division in the shoot apical meristem, this mutant shows a significant reduction in shoot growth and sensitivity to the hormone. In contrast, pin1 affects auxin transport, and abi1 mutants show reduced dormancy. The rga/gai double mutant would actually be taller because it lacks two major growth repressors.

138. (B) Severe dwarfism and an extremely small shoot apical meristem.
The ahk2 ahk3 ahk4 triple mutant lacks all three primary histidine kinase receptors for cytokinin. Because cytokinin is absolutely required for maintaining the pool of dividing cells in the shoot apical meristem, this mutant cannot maintain normal shoot growth. The result is a severely dwarfed plant with a tiny meristem that produces very few leaves, illustrating the essential role of cytokinin signaling in plant development.

139. (A) Auxin-mediated gravitropism and organogenesis.
The tomato diageotropica mutant is a classic tool for studying auxin biology. It exhibits a profound loss of sensitivity to auxin, which leads to horizontally growing roots and a complete lack of lateral root formation. By studying this mutant, researchers have gained insights into how auxin signals are perceived and how they regulate complex developmental processes like gravitropic curvature and the initiation of new organ primordia.

140. (C) It is defective in polar auxin efflux, leading to fused cotyledons.
The aux1 mutant is specifically defective in an auxin influx carrier, which is responsible for bringing auxin into cells. This defect leads to agravitropic root growth because the root cannot properly redistribute auxin. While auxin transport is disrupted, the aux1 mutation affects influx, not efflux. Mutants defective in polar auxin efflux, such as pin1, are the ones typically characterized by severe defects like fused cotyledons.

141. (D) Auxin and Cytokinin
Apical dominance is regulated by the antagonistic relationship between auxin and cytokinin. Auxin produced in the shoot apex travels down the stem and indirectly inhibits the outgrowth of axillary buds. Conversely, cytokinins, which are primarily synthesized in the roots and transported upward, promote the development of these buds. The balance between these two hormones determines the overall branching pattern and architecture of the plant.

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overcome the apical dominance of the primary shoot, stimulating the outgrowth of axillary buds. This results in the formation of a cluster of shoots that can be separated and subcultured.

160. (D) Benzylaminopurine (BAP) – Shoot multiplication
Benzylaminopurine is a widely used synthetic cytokinin in plant biotechnology. Its primary role in tissue culture is to promote the proliferation of shoots by releasing axillary buds from apical dominance. NAA is typically used for rooting, gibberellic acid for stem elongation, and 2,4-D for callus or embryo induction. Therefore, the combination of BAP and shoot multiplication is a correctly identified pair in commercial micropropagation.

161. (A) Auxin
Apical dominance is the phenomenon where the shoot apex inhibits the growth of axillary buds located further down the stem. This is primarily maintained by the continuous production of auxin in the young leaves and its active transport down the stem. This basipetal auxin flux acts as an indirect signal that suppresses bud outgrowth, ensuring that the plant allocates resources to vertical growth.

162. (C) Negative regulators that inhibit axillary bud outgrowth
Strigolactones are a class of hormones that play a crucial role in regulating plant architecture by inhibiting shoot branching. They act as negative regulators that work within or near the axillary buds to suppress their outgrowth. By coordinating with auxin and cytokinin, strigolactones ensure that the plant maintains the appropriate number of branches in response to environmental conditions and nutrient availability.

163. (A) Cytokinin
If an axillary bud is inhibited by apical dominance, it can often be released by the direct application of cytokinin. Cytokinins act as positive regulators of bud growth and can override the inhibitory signals provided by auxin and strigolactones. This localized treatment stimulates cell division within the bud, allowing it to grow out into a branch. This confirms the antagonistic role of cytokinin in shoot branching.

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164. (D) Arrest bud growth; upregulated by strigolactones, downregulated by cytokinins.
BRC1 is a key transcription factor that acts as a central integrator of hormonal signals within the axillary bud. Its primary function is to arrest bud growth. The expression of BRC1 is upregulated by strigolactones and abscisic acid, which inhibit branching. Conversely, its expression is downregulated by cytokinins, which promote branching. The level of BRC1 protein thus determines whether a bud will remain dormant or grow.

165. (A) I, II and V
Decapitation removes the primary source of auxin and disrupts the polar auxin transport stream. This leads to a rapid drop in auxin levels near the axillary buds. Without the inhibitory effect of the auxin flux, the axillary buds are released from dormancy and initiate growth. This process is also accompanied by an increase in local cytokinin levels and a decrease in strigolactones, both of which favor bud outgrowth.

166. (C) Continued suppression of axillary buds
When the shoot apex is removed, apical dominance is lost, and axillary buds normally begin to grow. However, if an agar block containing IAA is applied to the decapitated stump, the auxin will diffuse into the stem and mimic the signal from the original apex. This exogenous auxin maintains the suppression of the axillary buds, demonstrating that the inhibitory effect of the apex is chemically mediated by auxin transport.

167. (D) Establish its own polar auxin stream and export auxin to the stem.
The auxin canalization hypothesis suggests that bud outgrowth is limited by the ability of the bud to export its own auxin. For a bud to grow, it must establish a polar auxin stream that connects to the main vascular system of the stem. This export is facilitated by the polarization of PIN carriers. If the main stem already has high auxin levels, it prevents the bud from exporting its auxin, thus maintaining dormancy.

168. (A) Strigolactone
The max mutants in Arabidopsis and rms mutants in pea are characterized by an extremely bushy, highly branched phenotype. Research on these mutants was instrumental in identifying strigolactones as a new class of plant hormones. These genes are involved in either the biosynthesis

seed germination and early seedling growth. This inhibitory effect of glucose is closely linked to abscisic acid signaling, as glucose promotes ABA synthesis and enhances the plant's sensitivity to the hormone. This synergism ensures that seedling development is coordinated with the availability of carbon reserves and environmental stress.

151. (D) Skoog and Miller
In the 1950s, Folke Skoog and Carlos Miller performed ground-breaking experiments using tobacco pith tissue. They discovered that the relative concentrations of auxin and cytokinin in the culture medium could determine whether the tissue would remain as a callus or regenerate into roots or shoots. This discovery of hormonal control over organogenesis remains one of the most fundamental principles in plant tissue culture and biotechnology today.

152. (A) Roots
According to the Skoog and Miller model, the developmental fate of a callus is controlled by the auxin-to-cytokinin ratio. A high ratio of auxin to cytokinin promotes the formation of roots, a process known as rhizogenesis. This happens because high auxin levels stimulate the differentiation of vascular tissue and the initiation of root primordia. This principle is widely used in micropropagation to induce rooting in regenerated shoots.

153. (B) Indole-3-butyric acid (IBA).
Indole-3-butyric acid is a naturally occurring auxin that is more stable and often more effective than IAA for inducing roots. It is the most widely used compound in commercial horticulture for promoting adventitious rooting in stem cuttings. IBA's effectiveness is partly due to its slow conversion into IAA within the tissue, providing a steady supply of auxin that is ideal for the initiation of root primordia.

154. (B) Auxin and Cytokinin
Totipotency is the remarkable ability of a single plant cell to divide and differentiate into an entire plant. This process requires the coordinated action of both auxin and cytokinin, which are essential for driving the cell cycle through the G1-S and G2-M transitions. Without both hormones, differentiated cells cannot re-enter the cell cycle or undergo the dedifferentiation necessary to form a whole new organism.

155. (A) P-4, Q-1, R-2, S-3
The hormonal control of in vitro development is highly predictable. High auxin with low cytokinin induces roots. Low auxin with high cytokinin induces shoots. Intermediate levels of both result in unorganized callus growth. Somatic embryogenesis is often induced by a high concentration of the synthetic auxin 2,4-D, followed by a transfer to a hormone-free medium, which allows the embryos to mature and germinate.

156. (C) Unorganized mass of actively dividing parenchyma cells.
Callus is an undifferentiated mass of tissue that forms in response to wounding or during tissue culture. Biologically, it consists of actively dividing parenchyma cells that have lost their original identity. Callus tissue is highly plastic and can be induced to regenerate various organs or even entire plants by carefully adjusting the balance of auxin and cytokinin in the surrounding growth medium.

157. (D) High auxin concentrations are required for the maturation phase.
Somatic embryogenesis involves the formation of embryos from non-zygotic cells. While a high concentration of auxin, typically 2,4-D, is required to induce the formation of embryogenic cells, the presence of auxin actually inhibits their subsequent maturation. To allow the somatic embryos to develop through the globular, heart, and torpedo stages, they must be transferred to a medium with very low or no auxin.

158. (C) Inducing dedifferentiation of parenchyma into a root primordium.
The application of IBA to a stem cutting triggers a profound change in the cells near the cut surface. These differentiated parenchyma cells undergo dedifferentiation, re-entering the cell cycle to form a new meristematic region called a root primordium. This process is driven by the localized accumulation of auxin, which provides the necessary signals for the initiation and organized growth of new adventitious roots.

159. (B) Cytokinins
In micropropagation, the goal of the multiplication stage is to produce as many new shoots as possible. This is achieved by adding high concentrations of cytokinins, such as BAP, to the culture medium. These cytokinins

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177. (A) Developing seeds provide auxin and GA to drive fruit tissue expansion.
Successful fruit set and subsequent development are heavily dependent on hormonal signals from the developing seeds. After fertilization, the seeds become a rich source of auxins and gibberellins. these hormones stimulate the surrounding ovary tissues to divide and expand, transforming them into a mature fruit. In the absence of fertilization or seed development, hormone levels remain low, and the ovary typically abscises rather than developing further.

178. (C) Seed removal halts receptacle growth; restored by exogenous auxin.
Nitsch's classic experiment on strawberries demonstrated the importance of seed-derived signals for fruit growth. He showed that removing the tiny seeds, or achenes, from the surface of the strawberry receptacle caused it to stop growing. However, if the seedless receptacle was treated with exogenous auxin, its growth was restored. This proved that the achenes are the primary source of auxin required for the expansion of the fleshy fruit tissue.

179. (A) Ethephon
Pineapple plants are unusual because their flowering is strongly induced by ethylene. In commercial pineapple production, farmers use ethephon, which breaks down to release ethylene gas, to synchronize the flowering of the entire field. This allows for a uniform harvest and more efficient management. This application is a prime example of how understanding a plant's unique hormonal responses can be directly applied to improve agricultural productivity and efficiency.

180. (D) Polyamines are the primary universal hormones determining sex across all dioecious angiosperms.
Sex expression in plants is controlled by a variety of hormones, most notably ethylene and gibberellins, but their effects are not universal and vary between species. For example, ethylene promotes femaleness in cucumber, while gibberellin promotes maleness. While polyamines are involved in many aspects of floral development, they are not considered the primary universal hormones for sex determination. Sex expression is a complex trait regulated by multiple interacting signaling pathways.

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181. (B) Abscission zone
Abscission is the process by which a plant sheds its parts, such as leaves, fruits, or flowers. This occurs at a specific location called the abscission zone, which consists of a few layers of specialized cells. These cells are highly sensitive to hormonal signals, particularly ethylene and auxin. During abscission, these cells undergo structural changes and produce enzymes that break down the middle lamella, allowing the organ to separate cleanly from the plant.

182. (C) The flux of auxin from the leaf blade across the zone is maintained.
The auxin gradient theory of abscission proposes that the process is regulated by the balance of auxin across the abscission zone. As long as the leaf blade is healthy and produces a steady flux of auxin that travels through the petiole, the abscission zone remains insensitive to ethylene. This continuous auxin supply inhibits the production of cell wall-degrading enzymes, effectively delaying the shedding of the leaf until its functional life is over.

183. (D) Cellulases and polygalacturonases.
The final step in the abscission process is the physical separation of the organ from the stem. This is achieved by the secretion of hydrolytic enzymes that digest the cell wall and the middle lamella. The most important enzymes for this are cellulases and polygalacturonases. These enzymes are synthesized in response to ethylene signaling and work to break down the structural integrity of the abscission zone cells, leading to clean separation.

184. (A) Activation of the photosynthetic machinery in the abscission zone
Leaf abscission is a coordinated process that involves several metabolic and structural changes. These include the reduction of auxin transport, an increase in ethylene sensitivity, and the formation of a protective suberized layer on the stem. However, the activation of photosynthesis is not part of this process. In fact, abscission is typically associated with the cessation of photosynthesis and the mobilization of nutrients away from the organ being shed.

185. (A) P-1, Q-2, R-3, S-4
Abscission proceeds through four distinct phases. First, high auxin flux maintains the leaf and keeps the zone insensitive to ethylene. Next,

requires a specific period of exposure to cold and moisture before they can germinate. This ensures that the seeds do not sprout during a mid-winter thaw but wait until the spring when conditions are reliably favorable for seedling establishment and growth.

203. (A) Dormancy induced after seed shed, triggered by environment.
Primary dormancy is established during seed development on the mother plant. However, even non-dormant seeds can enter a state called secondary dormancy if they are exposed to unfavorable environmental conditions after they have been shed. For example, exposure to high temperatures or lack of light can trigger secondary dormancy, ensuring that the seed waits for the most opportune time to germinate, thereby increasing its chances of survival.

204. (C) Soaking the seed in a low concentration of GA3
Scarification refers to the physical or chemical treatment of the seed coat to make it permeable to water and gases. This can involve mechanical abrasion, acid treatment, or even the passage of the seed through an animal's digestive tract. While soaking seeds in gibberellins can help overcome physiological dormancy, it is not considered a form of scarification because it does not involve the physical breakdown of the external seed coat.

205. (B) I, II and III
Seed dormancy is a complex trait regulated by the interaction of ABA and GA. High ABA levels during maturation are essential for enforcing primary dormancy, while de novo GA synthesis is required to trigger germination. Importantly, it is the ratio of these two hormones that determines the seed's status. Statement IV is incorrect because it is high ABA, not GA, during development that leads to deeper and more persistent primary dormancy.

206. (B) After-ripening
After-ripening is the physiological process where seeds gradually lose their primary dormancy over time while being stored in a dry state. This process is common in many grasses and wildflowers. During after-ripening, the seed's sensitivity to ABA decreases while its sensitivity to GA increases. This ensures that seeds shed in the late summer do not germinate until the following year, coordinating their life cycle with the appropriate seasonal changes.

207. (B) Decreased ABA coupled with increased GA biosynthesis.
During the process of cold stratification, dormant seeds undergo significant biochemical changes that prepare them for germination. The primary internal change is a dramatic shift in the hormonal balance: the levels of the dormancy-promoting hormone ABA decline, while the capacity for gibberellin biosynthesis increases. By the end of the cold period, the high GA-to-ABA ratio allows the embryo to overcome its physiological constraints and begin the germination process.

208. (D) Application of high doses of ABA
Bud dormancy in trees is broken by environmental signals like winter chilling or by chemical treatments such as hydrogen cyanamide. Pruning can also stimulate growth by removing apical dominance. However, applying abscisic acid would actually reinforce bud dormancy rather than breaking it. ABA is the primary endogenous signal that maintains the dormant state, so increasing its concentration would prevent the buds from sprouting, even if other conditions were favorable.

209. (A) Vivipary (precocious germination on the mother plant).
Abscisic acid is absolutely required to prevent seeds from germinating while they are still attached to the mother plant. If the NCED enzyme, which is the rate-limiting step for ABA synthesis, is defective, the developing embryo will fail to enter dormancy. Instead, it will continue to grow, leading to a condition called vivipary. This phenomenon is famously seen in certain maize mutants and is a clear demonstration of ABA's essential role.

210. (D) Gibberellic acid.
In the malting process, barley seeds are germinated to activate enzymes that convert starch into fermentable sugars. To ensure that this process is fast and uniform across the entire batch, maltsters often add exogenous gibberellic acid. This hormone mimics the signal naturally produced by the embryo, stimulating the aleurone layer to synthesize and secrete high levels of alpha-amylase. This industrial application of plant hormones is a critical step in beer production.

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194. (C) Heavy application of gibberellins.
While ethylene, abscisic acid, and jasmonic acid are known to promote or accelerate the senescence process, gibberellins are generally not associated with inducing senescence. In fact, in some species, gibberellins can help maintain the greenness of tissues and delay certain aspects of aging. Environmental factors like darkness and nutrient deficiency are also major drivers of senescence, highlighting the complex interplay between internal and external signals in controlling leaf lifespan.

195. (B) I only
Programmed cell death is a fundamental process in plant development and occurs throughout the entire lifespan of the plant, not just at the end. For example, PCD is essential for the formation of xylem tracheary elements, the development of aerenchyma, and the response to certain pathogens. Senescence is a specific type of PCD that is uniquely characterized by the large-scale mobilization of nutrients before the final death of the cell.

196. (D) Monocarpic senescence
Monocarpic senescence is a dramatic process seen in many annual crops, such as wheat and soybeans, where the entire plant senesces and dies simultaneously after a single reproductive cycle. This is triggered by the massive demand for nutrients by the developing seeds, which act as powerful sinks. The mobilization of resources from the leaves and stems to the seeds eventually leads to the exhaustion and death of the vegetative tissues.

197. (B) ABA promotes senescence primarily under stress like drought.
Abscisic acid is a significant promoter of senescence, particularly when the plant is under environmental stress. During drought, ABA levels rise, which triggers both stomatal closure and the upregulation of senescence-associated genes. This accelerates the aging and shedding of older leaves, helping the plant to conserve water and resources. While it is not the only hormone involved, ABA's role as a stress-induced senescence signal is a vital survival mechanism.

198. (C) Chlorophyll degradation unmasking pre-existing carotenoids.
The characteristic yellow and orange colors seen in senescing leaves are due to the presence of carotenoids. These pigments are actually present in the chloroplasts throughout the leaf's life, where they assist in light harvesting. However, they are normally masked by the much more abundant green chlorophyll. During senescence, chlorophyll is broken down first, unmasking the more stable carotenoids and giving the leaves their distinctive autumn colors.

199. (D) Markedly delayed leaf senescence (stay-green phenotype).
By placing the IPT gene, which encodes the rate-limiting enzyme for cytokinin synthesis, under the control of a senescence-specific promoter, scientists created a self-regulating system. As the leaf begins to senesce, the promoter activates the IPT gene, leading to a localized burst of cytokinin. This increase in cytokinin then blocks the senescence process, resulting in a "stay-green" plant that maintains its photosynthetic capacity for a significantly longer period.

200. (A) Mitochondria are destroyed very early, halting all cellular respiration before nutrient export begins.
The cellular dismantling during senescence is a highly orderly process. Contrary to popular belief, mitochondria are one of the last organelles to be destroyed. They must remain functional to provide the ATP and metabolic intermediates needed to drive the energy-intensive process of nutrient remobilization. Chloroplasts are usually the first to go, followed by the cytoplasm, while the nucleus and mitochondria remain active until the very late stages of the process.

NODIA

201. (B) Abscisic acid (ABA) and Gibberellin (GA).
The decision to germinate or remain dormant is controlled by a delicate hormonal balance within the seed. Abscisic acid is the primary hormone that establishes and maintains dormancy, preventing germination even under favorable conditions. Gibberellins, on the other hand, are required to break dormancy and stimulate the expansion of the embryo. The relative levels and sensitivity to these two hormones dictate whether the seed will remain quiescent or begin to grow.

202. (B) Prolonged periods of cold, moist conditions.
Stratification is a horticultural technique that mimics the natural experience of seeds during winter. Many species from temperate regions have evolved a dormancy mechanism that

maintaining cell turgor.
(B) It is an integral component of ATP, nucleic acids, and phospholipids.
(C) It forms disulfide bridges to stabilize protein tertiary structures.
(D) It acts strictly as an enzyme activator for rubisco.

2021

19. Calcium functions largely as a structural component in the plant cell wall, where it binds strongly to:
(A) Cellulose microfibrils
(B) Hemicellulose
(C) Lignin precursors
(D) Pectins to form calcium pectate

2012

20. Sulfur is primarily taken up by roots in which form?
(A) Sulfate (SO_4^{2-})
(B) Elemental sulfur (S)
(C) Hydrogen sulfide (H_2S)
(D) Sulfite (SO_3^{2-})

2014

21. The micronutrient required for the synthesis of indoleacetic acid (IAA) from tryptophan is:
(A) Manganese
(B) Zinc
(C) Boron
(D) Copper

2005

22. Which of the following roles is INCORRECTLY paired with its micronutrient?
(A) Boron: Electron transport in the cytochrome b6f complex
(B) Manganese: Oxygen evolution in the Photosystem II complex
(C) Molybdenum: Essential component of the nitrate reductase enzyme
(D) Iron: Structural component of both cytochromes and ferredoxin

2001

23. Copper is an essential constituent of which vital photosynthetic electron carrier?
(A) Ferredoxin
(B) Plastoquinone
(C) Plastocyanin
(D) Cytochrome c

2003

24. Chlorine functions in the plant primarily as a:
(A) Structural component in the lipid bilayer of plant cell membranes.
(B) Osmoregulation and co-factor in the water-splitting complex of PSII.
(C) Essential catalyst for the biological process of nitrogen fixation.
(D) Core atom required for the synthesis of specific stress-response hormones.

2012

25. Consider the following statements regarding the role of Boron in plants:
I. It is essential for pollen tube growth and germination.
II. It is involved in cell wall cross-linking via rhamnogalacturonan II.
III. It is a major component of the nitrogenase enzyme complex.
Which of the following represents the correct combination of statements?
(A) I and II
(B) II and III
(C) I and III
(D) I only

2024

26. A highly characteristic visual symptom of iron deficiency in plants is:
(A) Necrotic spots on older leaves
(B) Interveinal chlorosis on the youngest leaves
(C) Purple coloration of the stems and petiole
(D) Stunted growth and hooked leaf tips

2001

27. "Whiptail" disease in cauliflower is a classic symptom of the deficiency of which nutrient?
(A) Molybdenum
(B) Zinc
(C) Boron
(D) Copper

2006

28. Blossom-end rot in tomatoes and bitter pit in apples are physiological disorders primarily associated with a localized deficiency of:
(A) Potassium
(B) Calcium
(C) Magnesium
(D) Phosphorus

2021

29. Which of the following agronomic practices is most effective for correcting zinc deficiency in flooded rice systems (Khaira disease)?
(A) Soil application of elemental sulfur to reduce alkalinity.
(B) Application of zinc sulfate to soil or as a

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211. (A) Climacteric
Fruits are classified into two groups based on their ripening physiology. Climacteric fruits, such as tomatoes, bananas, and apples, exhibit a dramatic increase in both respiration and ethylene production at the beginning of the ripening process. This burst of ethylene is essential for coordinating the various changes in color, texture, and flavor. In contrast, non-climacteric fruits ripen more gradually and do not show this characteristic spike in ethylene or respiration.

212. (D) Autocatalytic surge of ethylene driving ripening.
In climacteric fruits, ethylene production occurs in two distinct stages. System 1 represents the basal, low-level synthesis found in young fruits. Once ripening is triggered, the fruit transitions to System 2, which is a massive, autocatalytic burst of ethylene. In this system, the presence of ethylene actually stimulates more ethylene production. This positive feedback loop ensures that the entire fruit ripens rapidly and uniformly once the process has been initiated.

213. (B) Grape
Grapes are a classic example of non-climacteric fruits. Unlike apples, bananas, or tomatoes, grapes do not show a surge in ethylene or respiration during ripening. Instead, they ripen slowly on the vine and do not continue to ripen once they are harvested. This means that non-climacteric fruits must be harvested at peak ripeness to ensure the best quality, as they lack the autocatalytic ethylene system that drives post-harvest ripening.

214. (C) Massive lignification of the pericarp cell walls
Fruit ripening involves several coordinated changes designed to make the fruit attractive to seed dispersers. These include the degradation of chlorophyll, the synthesis of pigments and sugars, and the softening of tissues through the action of wall-degrading enzymes. However, massive lignification is not a feature of fleshy fruit ripening. Lignification makes tissues hard and woody, which would be the opposite of the softening process required for edible fleshy fruits.

215. (B) I and V
There are several misconceptions about fruit ripening. Statement I is incorrect because 1-MCP is an inhibitor that delays ripening, not an accelerator. Statement V is also incorrect because many climacteric fruits, like bananas and avocados, are harvested while still green and firm because they have the ability to ripen off the plant. Other treatments like silver thiosulfate and potassium permanganate are indeed used to manage ethylene and extend post-harvest life.

NODIA

216. (A) Irreversible binding to ethylene receptors, blocking perception.
1-Methylcyclopropene is a powerful tool in post-harvest technology. It is a gaseous compound that binds to ethylene receptors with much higher affinity than ethylene itself. By irreversibly blocking the receptors, 1-MCP prevents the plant from perceiving any ethylene in the environment. This effectively "freezes" the ripening or senescence process, allowing fruits and flowers to remain fresh for a significantly longer period during transport and storage.

217. (B) Replaces copper in the receptor, blocking signaling.
Silver thiosulfate is used to extend the life of cut flowers because the silver ion is a potent inhibitor of ethylene action. The ethylene receptor requires a copper ion to bind the hormone. The silver ion can replace the copper in the binding pocket, but it cannot facilitate the signaling response. This effectively blocks the flower's ability to respond to ethylene, preventing premature wilting and abscission of the petals.

218. (B) III - I - II - IV
The climacteric ripening process follows a logical molecular and physiological sequence. First, master transcription factors like RIN are activated. These factors then induce the expression of ethylene biosynthetic genes (ACS and ACO). This leads to the autocatalytic System 2 ethylene burst. Finally, this high level of ethylene triggers the downstream execution of ripening, including color changes, softening of the cell walls, and the development of flavor and aroma.

219. (A) Expressing antisense RNA to downregulate PG activity.
The Flavr Savr tomato was the first genetically modified food to be commercially sold. It was engineered to have a longer shelf life by reducing the activity of polygalacturonase, an enzyme that breaks down cell wall pectin and causes

CHAPTER 06
Mineral Nutrition

2009

1. Arnon and Stout (1939) established the criteria of essentiality for plant nutrients. Which of the following is one of their original criteria?
(A) The element must be readily replaceable by another element of similar chemical properties.
(B) A plant cannot complete its vegetative or reproductive life cycle in the absence of the element.
(C) The element is only required for the synthesis of secondary metabolites.
(D) The element must increase the overall biomass without being directly involved in metabolism.

2010

2. If a newly discovered element promotes growth in a specific hyperaccumulator plant but its absence does not prevent the plant from producing viable seeds, how should this element be classified according to classical criteria?
(A) Essential element
(B) Macronutrient
(C) Beneficial element
(D) Structural element

2004

3. Who proposed the concept of "functional nutrients," expanding upon Arnon and Stout's criteria to include elements essential for specific plants or metabolic pathways?
(A) E. Epstein
(B) D.I. Arnon
(C) J. von Liebig
(D) A.D. Nicholas

2009

4. The Law of Minimum, which states that plant growth is dictated not by total resources available, but by the scarcest resource, was formulated by:
(A) Justus von Liebig
(B) Arnon and Stout
(C) Stephen Hales
(D) Julius von Sachs

2010

5. For the following question, choose the correct option from (A), (B), (C), and (D) based on the Assertion (A) and Reason (R) provided.
Assertion (A): Sodium (Na) is not considered a globally essential element for all higher plants.
Reason (R): Sodium does not meet the strict criteria of essentiality as most plants can complete their life cycle entirely without it.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2024

6. Which of the following groups contains only essential micronutrients?
(A) Fe, Mn, Zn, Mg
(B) Cu, B, Mo, Ni
(C) Cl, Na, Si, Co
(D) Zn, Cu, S, Ca

2012

7. Silicon (Si) is considered a beneficial element particularly important for which of the following plant families to enhance structural rigidity and pest resistance?
(A) Poaceae
(B) Fabaceae
(C) Brassicaceae
(D) Solanaceae

2008

8. Which of the following statements regarding beneficial elements is INCORRECT?
(A) Cobalt is essential for nitrogen fixation in legumes.
(B) Selenium can replace sulfur in certain amino acids in accumulator plants.
(C) Silicon directly participates in the electron transport chain during photosynthesis.
(D) Sodium can substitute for potassium to a limited extent in some C4 plants.

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strengthen the stems is a standard practice to prevent this issue.

228. (A) P-2, Q-1, R-3, S-4
Plant growth regulators have diverse commercial applications. Ethephon is used to accelerate the ripening of fruits like tomatoes and sugarcane. NAA is commonly applied to prevent the premature drop of apples before harvest. Gibberellic acid is used in the grape industry to increase berry size and bunch length. Finally, trinexapac-ethyl is a growth retardant used in turfgrass management to slow down vertical growth and reduce the need for frequent mowing.

229. (B) Reducing mowing frequency and enhancing density by limiting elongation.
In professional turf management, growth retardants like trinexapac-ethyl are used to manage the growth of grass on golf courses and athletic fields. By inhibiting gibberellin synthesis, these chemicals slow down the rate of vertical leaf elongation. This not only reduces the need for frequent mowing but also encourages the plant to divert resources into lateral growth and root development. The result is a denser, more durable, and higher-quality turf surface.

230. (C) Atrazine and Glyphosate are both classified functionally as synthetic auxins.
This statement is incorrect because atrazine and glyphosate have completely different modes of action compared to synthetic auxins. Atrazine is a photosystem II inhibitor that blocks electron transport, while glyphosate inhibits the EPSP synthase enzyme in the shikimate pathway. Synthetic auxins, like 2,4-D, specifically mimic the hormone IAA to cause uncoordinated growth. The distinction between these classes of herbicides is fundamental to their specific uses and selectivity in agriculture.

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fruit softening. This was achieved by introducing an antisense gene that blocked the expression of the natural PG gene. This allowed the fruit to remain firm for longer, reducing damage during shipping and handling.

220. (B) 1–3% oxygen and 1–5% carbon dioxide
Controlled atmosphere storage is a technique used to significantly extend the storage life of fruits like apples. By lowering the oxygen concentration to 1-3% and increasing the carbon dioxide to 1-5%, the rate of cellular respiration is dramatically slowed. Furthermore, these conditions inhibit the synthesis and action of ethylene. This slow-down of metabolism allows apples to be stored for many months while still maintaining their crispness and flavor.

221. (D) ent-kaurene oxidase in the GA pathway.
Paclobutrazol is a widely used triazole growth retardant that produces a dwarfing effect by interfering with gibberellin biosynthesis. It specifically targets and inhibits the enzyme ent-kaurene oxidase, which is a cytochrome P450 monooxygenase. By blocking the conversion of ent-kaurene into ent-kaurenoic acid, paclobutrazol effectively lowers the levels of bioactive gibberellins in the plant, resulting in reduced internode elongation and a more compact growth habit.

222. (C) Gibberellin synthesis
Chlormequat chloride, also known as Cycocel, is a synthetic growth regulator that acts as an anti-gibberellin. It works by inhibiting the early steps of the GA biosynthetic pathway, specifically the enzymes that convert geranylgeranyl diphosphate into ent-copalyl diphosphate. By reducing the pool of precursors available for active gibberellin production, Chlormequat limits stem elongation in cereal crops. This makes the plants shorter and more resistant to lodging in the field.

223. (B) Stable accumulation causing uncoordinated growth and vascular disruption.
Synthetic auxins like 2,4-D and Dicamba are used as herbicides because they are much more stable within the plant than natural IAA. When applied at high doses, they accumulate in the growing points and trigger massive, uncontrolled cell division and expansion. This leads to characteristic symptoms like epinasty (stem twisting) and the disruption of the vascular tissues. This uncoordinated growth eventually exhausts the plant's resources and leads to its death.

224. (D) Increased intermodal elongation and enhanced biomass of forage crops
The primary goal of applying anti-gibberellins in agriculture and horticulture is to reduce plant height and produce more compact plants. This is beneficial for preventing lodging in cereals, maintaining the size of ornamental plants, and improving fruit set by diverting resources from vegetative growth. However, increasing internodal elongation and biomass is the opposite of what these retardants do; such effects would be achieved by applying gibberellins themselves.

225. (A) Both A and R are true and R is the correct explanation of A.
Prohexadione-calcium is a highly effective growth retardant that targets the final stages of gibberellin biosynthesis. It is structurally similar to 2-oxoglutarate, which is a required co-substrate for several GA-oxidizing enzymes. By acting as a competitive inhibitor, prohexadione-calcium blocks the activity of GA 3-oxidase, which converts inactive precursors into biologically active GA1 or GA4. This precisely lowers the concentration of active hormone, effectively controlling plant height and vegetative growth.

226. (C) Growth retardants
Compounds that interfere with the synthesis or signaling of gibberellins are collectively known as growth retardants. These chemicals are used extensively in horticulture and agriculture to control plant size, improve crop standing, and enhance the visual appeal of ornamental plants. By specifically reducing internode elongation without affecting other developmental processes, these retardants allow for the production of compact, sturdy plants that are better suited for commercial production and transport.

NODIA

227. (A) Permanent stem bending near ground level due to wind or rain.
Lodging is a serious problem in cereal production where the stems of plants like wheat or barley bend or break near the ground. This often happens due to heavy wind, rain, or excessive nitrogen fertilization, which leads to weak, spindly stems. Lodging makes mechanical harvesting difficult and can significantly reduce grain quality and yield. Using growth retardants to shorten and

2010

9. Why is Nickel (Ni) classified as an essential micronutrient for higher plants?
(A) It serves as a functional substitute for iron in ferredoxin during iron deficiency.
(B) It functions as the primary electron acceptor in the reaction center of Photosystem II.
(C) It is required for the enzymatic biosynthesis of the complex chlorophyll porphyrin ring.
(D) It is the structural metal component of urease for urea metabolism.

2008

10. Which of the following elements is structurally categorized as a macronutrient but often functions similarly to micronutrients by forming transient covalent bonds in coenzymes and prosthetic groups?
(A) Calcium
(B) Potassium
(C) Sulfur
(D) Phosphorus

2011

11. "Hidden hunger" in plant nutrition refers to a condition where:
(A) Yield is limited by nutrient deficiency without distinct visual symptoms.
(B) Severe visual deficiency symptoms are present while maintaining normal yield.
(C) The application of nutrients reduces total yield due to excessive accumulation.
(D) Roots are unable to absorb nutrients despite high soil levels due to low pH.

2002

12. The "Steenbjerg effect" is best described as:
(A) Yield increases immediately upon the addition of a limiting soil nutrient.
(B) Potassium has an antagonistic effect on the absorption of magnesium ions.
(C) Mycorrhizal plants engage in the luxury consumption of available phosphorus.
(D) Nutrient concentration decreases as initial growth responds to application.

2023

13. The concentration of a nutrient in plant tissue just below the level that gives maximum growth or yield is defined as the:
(A) Critical nutrient concentration
(B) Maximum toxicity threshold
(C) Optimal adequate range
(D) Luxury consumption level

2005

14. When a plant absorbs a nutrient beyond its requirement for maximum growth without any further increase in biomass, this phenomenon is called:
(A) Hidden hunger
(B) Phytoextraction
(C) Luxury consumption
(D) Phytostabilization

2004

15. Match the concepts in List I with the descriptions in List II.
List I: (Concept)
P. Hidden hunger
Q. Luxury consumption
R. Critical concentration
S. Steenbjerg effect
List II: (Description)
1. Yield reduction due to dilution effect upon initial nutrient application
2. Tissue concentration where yield is 10% below maximum
3. Yield restriction without visible deficiency symptoms
4. Uptake of nutrients not leading to yield increases
(A) P-3, Q-4, R-2, S-1
(B) P-1, Q-4, R-2, S-3
(C) P-3, Q-2, R-1, S-4
(D) P-2, Q-3, R-4, S-1

2021

16. Which macronutrient is centrally located in the porphyrin ring of the chlorophyll molecule?
(A) Iron
(B) Calcium
(C) Potassium
(D) Magnesium

2019

17. Potassium (K) plays a critical role in plant physiology primarily by:
(A) Forming the structural backbone of nucleic acids.
(B) Regulating stomatal opening and closing via osmotic potential.
(C) Acting as a component of the middle lamella in cell walls.
(D) Serving as an electron donor in the light reactions of photosynthesis.

2012

18. Which statement correctly describes the biochemical role of phosphorus in plants?
(A) It is the primary element responsible for

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the induction phase occurs as auxin flux drops and ethylene sensitivity increases. During the execution phase, hydrolytic enzymes break down the cell walls. Finally, in the post-abscission phase, a protective scar layer is formed. This sequence ensures that the plant sheds organs efficiently while protecting itself from pathogens.

186. (B) Ethylene
Defoliants are agricultural chemicals used to induce premature leaf drop, facilitating mechanical harvesting in crops like cotton. Most defoliants work by causing tissue damage or stress that stimulates the massive production of ethylene within the leaves. This surge in ethylene overcomes the inhibitory effect of auxin and triggers the abscission process. By accelerating natural senescence and leaf fall, these chemicals help to streamline the harvesting process.

187. (A) Decline of auxin in the distal side relative to the proximal side.
The sensitivity of cells in the abscission zone to ethylene is determined by the auxin gradient. When the level of auxin on the distal side (the leaf side) of the zone drops relative to the proximal side (the stem side), the zone becomes highly responsive to ethylene. This change in sensitivity is a critical prerequisite for the induction of the cell wall-degrading enzymes that will ultimately carry out the abscission process.

188. (C) Cytokinin
While ethylene and abscisic acid are well known for promoting the shedding of plant organs, cytokinins generally act as inhibitors or delayers of the abscission process. Cytokinins achieve this by maintaining the health and photosynthetic activity of the leaf and by preventing the drop in auxin levels. By delaying senescence, cytokinins ensure that the organ remains functional and attached to the plant for a longer period.

189. (D) Reduce transpirational surface area to conserve water.
Premature leaf abscission is a common adaptive response to severe environmental stress, particularly drought. By shedding some of its leaves, the plant reduces its total transpirational surface area, which significantly lowers the rate of water loss. This self-pruning mechanism helps the plant maintain its remaining water reserves and increases its chances of survival during prolonged periods of water scarcity. It is a vital strategy for long-term stress tolerance.

NODIA

190. (C) Synthetic auxins (e.g., 2,4-D or NAA).
Pre-harvest fruit drop is a significant problem in many orchards, as it can lead to massive yield losses just before harvesting. To prevent this, growers often apply synthetic auxins such as NAA or 2,4-D. These chemicals maintain a high auxin signal at the abscission zone of the fruit pedicel, which prevents the induction of the cell wall-degrading enzymes and effectively "glues" the fruit to the tree until the desired harvest time.

191. (B) Salvaging and remobilizing nutrients to younger organs or seeds.
Senescence is a highly organized physiological process that precedes the death of an organ. Its primary biological function is to recycle nutrients, such as nitrogen, phosphorus, and minerals, from the aging tissue to more active parts of the plant, such as developing seeds or young leaves. This nutrient salvage is essential for the plant's overall efficiency and survival, particularly in environments where soil nutrients are limiting.

192. (D) Proteases, lipases, and nucleases
The expression of senescence-associated genes is a hallmark of the aging process in leaves. These genes encode various hydrolytic enzymes, including proteases that break down proteins, lipases that degrade lipids, and nucleases that digest nucleic acids. The activation of these enzymes allows the plant to dismantle its cellular components in a controlled manner, converting macromolecules into soluble forms that can be easily transported and reused in other tissues.

193. (A) Cytokinin
Cytokinins are the most potent endogenous inhibitors of leaf senescence. They work by maintaining the integrity of chloroplasts and the activity of the photosynthetic machinery. The application of cytokinins can significantly delay the onset of yellowing and nutrient mobilization. This effect, which involves both the suppression of chlorophyll degradation and the promotion of nutrient sinks, is crucial for coordinating the lifespan of different organs across the plant body.

foliar spray.
(C) Heavy application of diammonium phosphate to the root zone.
(D) Liming the soil to increase the pH value above 8.0 units.

2018

30. Identify the correct pair of nutrient deficiency and its specific indicator plant.
(A) Potassium - Potato
(B) Boron - Maize
(C) Molybdenum - Sugarcane
(D) Calcium - Oat

2002

31. In waterlogged soils, the redox potential drops significantly. Under such highly reducing conditions, which transformation predominantly occurs?
(A) Ferrous iron is oxidized to ferric iron forms.
(B) Manganese is oxidized to insoluble tetravalent forms.
(C) Sulfate is reduced to toxic hydrogen sulfide.
(D) Ammonium is rapidly nitrified to nitrate forms.

2006

32. As soil pH increases from 6.5 to 8.5, the availability of most micronutrients generally:
(A) Increases due to the enhanced solubility of metal ions.
(B) Remains unchanged regardless of the soil acidity level.
(C) Increases primarily for iron and manganese availability.
(D) Decreases as they precipitate as insoluble hydroxides.

2005

33. Which essential nutrient's availability actually increases as soil pH rises above 7.0, distinguishing it from most other micronutrients?
(A) Zinc
(B) Iron
(C) Molybdenum
(D) Copper

2022

34. High concentrations of aluminum (Al) in highly acidic soils ($pH < 4.5$) restrict plant growth primarily by:
(A) Inducing toxic accumulations within the shoot apex tissues.
(B) Inhibiting root elongation and restricting nutrient uptake.
(C) Degrading the chlorophyll molecules within the leaf lamina.
(D) Reversing the transport direction of the primary xylem sap.

2025

35. Read the following statements regarding soil factors affecting nutrient availability:
I. High organic matter generally increases micronutrient availability via chelation.
II. Low soil temperatures typically enhance phosphorus uptake by increasing root membrane fluidity.
III. Soil compaction decreases the diffusion rate of potassium to the root surface.
IV. A low redox potential increases the solubility of iron and manganese.
Which of the following represents the INCORRECT combination of statements?
(A) I and II
(B) III and IV
(C) II only
(D) IV only

2017

36. The Apparent Free Space (AFS) in plant roots comprises which two components?
(A) Symplast and Tonoplast
(B) Vacuolar space and Cytoplasm
(C) Xylem vessels and Phloem sieve tubes
(D) Water Free Space (WFS) and Donnan Free Space (DFS)

2014

37. The Donnan Free Space (DFS) is characterized by fixed negative charges located primarily on the:
(A) Phosphate groups of membrane phospholipids
(B) Amino groups of structural proteins
(C) Carboxyl groups of cell wall pectins
(D) Hydroxyl groups of cellulose

2015

38. Passive ion absorption into the Apparent Free Space (AFS) of roots is primarily driven by:
(A) Diffusion and mass flow
(B) ATP hydrolysis
(C) Symporter carrier proteins
(D) The proton motive force

2016

39. Which of the following is INCORRECT regarding the Water Free Space (WFS)?
(A) Ions in the space freely exchange with the external solution.
(B) The volume constitutes a significant portion of the apoplast.

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2017

121. A rapid increase in plant growth upon fertilizer application can sometimes lead to a temporary decrease in the tissue concentration of that nutrient. This is known as:
(A) Antagonistic uptake
(B) The dilution effect
(C) The toxicity threshold
(D) Synergistic accumulation

2014

122. At the "adequate zone" of a nutrient response curve, further increases in tissue nutrient concentration result in:
(A) Exponential increases in yield
(B) Severe visual deficiency symptoms
(C) Immediate plant death
(D) No significant change in yield

2023

123. Nitrogen is structurally vital in plants because it is a direct constituent of all the following except:
(A) Lignin
(B) Amino acids
(C) Nucleotides
(D) Chlorophyll

2023

124. Magnesium acts as a crucial cofactor in phosphorylation reactions because it binds to:
(A) The active site of rubisco
(B) ATP, forming a Mg-ATP complex required by kinases
(C) The nitrate transporter
(D) Calmodulin

2012

125. For the following question, choose the correct option from (A), (B), (C), and (D) based on the Assertion (A) and Reason (R) provided.
Assertion (A): Potassium deficiency often manifests as marginal chlorosis and necrosis on the older leaves of a plant.
Reason (R): Potassium is highly mobile within the plant, and during deficiency, it is retranslocated from older leaves to younger, actively growing tissues.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2010

126. Molybdenum is essential for the function of which of the following enzymes?
(A) Urease
(B) Superoxide dismutase
(C) Carbonic anhydrase
(D) Nitrogenase and Nitrate Reductase

2018

127. Which trace element is essential for the formation of the ureide compounds used for nitrogen transport in certain nitrogen-fixing legumes?
(A) Molybdenum
(B) Chlorine
(C) Zinc
(D) Iron

2017

128. Zinc is an essential cofactor for carbonic anhydrase, which catalyzes the hydration of CO_2. Where is this enzyme predominantly found in C3 plants?
(A) Xylem sap
(B) Root tip meristems
(C) Chloroplast stroma
(D) Vacuole

2013

129. "Little leaf" of mango and "rosette" of apple are classical symptoms associated with the deficiency of:
(A) Iron
(B) Manganese
(C) Calcium
(D) Zinc

2006

130. To immediately correct acute iron chlorosis in high-value horticultural crops growing on highly alkaline calcareous soils, the best approach is to apply:
(A) Soil application of iron sulfate
(B) Foliar spray of iron chelates (e.g., Fe-EDTA or Fe-EDDHA)
(C) Heavy irrigation to leach out calcium
(D) Foliar spray of urea

2002

131. Manganese toxicity in plants often appears as brown spots on older leaves accompanied by chlorosis. This is commonly referred to as:
(A) Crinkle leaf
(B) Khaira disease
(C) Grey speck
(D) Dieback

NODIA

(C) Primary active transporter pumping protons into the vacuole.
(D) Sensor kinase responsible for detecting membrane stretch.

2008

50. Sodium-proton (Na^+/H^+) antiporters on the tonoplast are crucial for salinity tolerance because they:
(A) Excrete sodium directly into the external soil solution.
(B) Compartmentalize toxic sodium ions into the vacuole.
(C) Transport protons out of the cell to neutralize alkalinity.
(D) Synthesize ATP molecules using the existing sodium gradient.

2021

51. In the context of ion uptake kinetics, what does the K_m (Michaelis constant) signify?
(A) The maximum rate of ion uptake into the plant root system.
(B) Minimum concentration required for a carrier to bind an ion.
(C) Total number of carrier proteins present in the membrane.
(D) External ion concentration where uptake rate is half $V_{\{}\max_{\}}$.

2011

52. The High-Affinity Transport System (HATS) for nutrient uptake usually operates when the external nutrient concentration is:
(A) Extremely low (micromolar range)
(B) In the millimolar range
(C) Toxic to the plant
(D) Highly variable due to rainfall

2025

53. Compared to HATS, the Low-Affinity Transport System (LATS) generally exhibits:
(A) Exhibits a much lower K_m value for specific nutrient ions.
(B) Requires ATP hydrolysis for every single ion transported.
(C) Linear uptake kinetics without saturation at high levels.
(D) Functions only under conditions of severe nutrient starvation.

2006

54. Why does ion uptake kinetics often exhibit a dual-phasic or multiphasic curve (Epstein's classical model) when plotted over a wide range of external concentrations?
(A) Distinct transport systems operate at different ranges.
(B) Due to the alternating opening and closing of aquaporins.
(C) Because roots rapidly alter their internal cytoplasmic pH.
(D) Because Nernst equilibrium shifts drastically with levels.

2022

55. Match the kinetic parameters in List I with the characteristics in List II.
List I: (Kinetic Parameters/Terms)
P. $V_{\{}\max_{\}}$
Q. K_m
R. HATS
S. LATS
List II: (Characteristics)
1. Operates at low external concentrations
2. Indicator of carrier affinity for an ion
3. Nonsaturating at moderate to high concentrations
4. Maximum uptake velocity of the carrier system
(A) P-1, Q-2, R-4, S-3
(B) P-3, Q-1, R-4, S-2
(C) P-4, Q-2, R-1, S-3
(D) P-1, Q-2, R-3, S-4

2024

56. The radial pathway where water and solutes travel continuously through the interconnected cytoplasm of adjacent cells via plasmodesmata is known as the:
(A) Transcellular pathway
(B) Symplastic pathway
(C) Vacuolar pathway
(D) Apoplastic pathway

2016

57. The apoplastic movement of ions through the root cortex is primarily blocked at the endodermis by the:
(A) Tonoplast
(B) Plasma membrane
(C) Casparian strip
(D) Middle lamella

2023

58. Which radial transport pathway requires solutes to repeatedly cross plasma membranes from cell to cell?
(A) Symplastic pathway
(B) Apoplastic pathway
(C) Vascular pathway

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(C) Solutes enter the space through the process of simple diffusion.
(D) Volume where anions are repelled by fixed negative charges.

2002

40. Unlike the Apparent Free Space, the symplastic pathway for ion movement requires:
(A) Movement solely through intercellular air spaces
(B) Crossing a semi-permeable plasma membrane
(C) Bulk flow driven by transpiration pull
(D) Passage through dead sclerenchyma cells

2010

41. The Nernst equation is used in membrane bioenergetics to determine the:
(A) The specific rate of ATP hydrolysis by plasma membrane H-ATPases.
(B) The total hydraulic conductivity of the primary root system.
(C) Equilibrium potential for a specific ion across a membrane.
(D) Minimum activation energy required for carrier protein transport.

2004

42. If the observed membrane potential is significantly more negative than the Nernst equilibrium potential for potassium (K^+), it indicates that:
(A) K^+ is currently at thermodynamic electrochemical equilibrium.
(B) A thermodynamic driving force exists for passive inward K^+ movement.
(C) K^+ transport is occurring exclusively via the symplastic route.
(D) K^+ is actively pumped into the cell against its gradient.

2006

43. In plant cells, the primary electrogenic pump responsible for generating the resting membrane potential (often -100 to -200 mV) is the:
(A) Plasma membrane H^+-ATPase
(B) Na^+/K^+ ATPase
(C) Ca^{2+} pump
(D) ABC transporter

2025

44. The proton motive force generated across the plasma membrane consists of which two gradients?
(A) ATP gradient and temperature gradient
(B) Gravity gradient and osmotic gradient
(C) Electrical potential gradient and pH gradient
(D) Sucrose gradient and pressure gradient

2017

45. For the following question, choose the correct option from (A), (B), (C), and (D) based on the Assertion (A) and Reason (R) provided.
Assertion (A): Secondary active transport of anions into plant roots utilizes the proton motive force.
Reason (R): Anion-proton symporters couple the thermodynamically downhill movement of protons to the thermodynamically uphill movement of anions.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2011

46. Which transport proteins facilitate the passive, rapid movement of ions down their electrochemical gradient and are often gated?
(A) Ion channels
(B) Primary active pumps
(C) Symporters
(D) Antiporters

2021

47. The transport mechanism where one solute is moved inward while another solute is simultaneously moved outward across the membrane by the same carrier is called:
(A) Uniport
(B) Symport
(C) Antiport
(D) Aquaporin transport

2013

48. Which of the following is true regarding carrier proteins compared to ion channels?
(A) Typically exhibit a much faster transport rate than ion channels.
(B) Are never involved in the process of primary active transport.
(C) Form permanently open and unregulated pores within the membrane.
(D) Undergo conformational changes to transfer bound ions.

2011

49. The vacuolar H^+-pyrophosphatase (V-PPase) functions as a:
(A) Secondary active transporter for the movement of sucrose.
(B) Passive ion channel for the transport of magnesium ions.

NODIA

(C) Boron is universally highly mobile in the phloem of all plant species.
(D) Magnesium is highly mobile in the phloem.

2025

70. Transfer cells play a crucial role in xylem-to-phloem nutrient exchange. They are characterized by:
(A) Extensive plasma membrane invaginations to increase surface area
(B) Thick suberized walls that prevent water loss
(C) Complete absence of mitochondria
(D) Large central vacuoles storing toxic secondary metabolites

2012

71. In foliar application of fertilizers, the primary structural barrier restricting the entry of aqueous nutrient solutions into the leaf is the:
(A) Epidermal cell wall
(B) Stomatal pore
(C) Palisade mesophyll
(D) Cuticle

2005

72. What are ectodesmata?
(A) Direct connections between the xylem and phloem cells.
(B) Modified plasmodesmata connecting guard to subsidiary cells.
(C) Submicroscopic polar pathways in the leaf cuticle.
(D) Suberized pores located within the Casparian strip tissue.

2008

73. Which environmental factor significantly enhances the absorption efficiency of foliar-applied nutrients?
(A) High relative humidity
(B) Freezing temperatures
(C) High wind velocity
(D) Very low soil moisture

2019

74. Foliar nutrition is most highly recommended in which of the following scenarios?
(A) Supplying the entire seasonal nitrogen requirement of wheat
(B) Applying basal doses of rock phosphate before sowing
(C) Correcting iron chlorosis in alkaline, calcareous soils
(D) Overcoming severe drought stress in deep-rooted perennials

2003

75. Consider the following statements regarding foliar nutrition:
I. Surfactants are added to foliar sprays to decrease the contact angle of droplets on the leaf.
II. Nutrients absorbed via leaves cannot be translocated to roots.
III. Urea is an effective foliar nitrogen source due to its high cuticular permeability.
IV. Foliar application rates must be carefully controlled to avoid leaf burn.
Which of the following represents the INCORRECT combination of statements?
(A) I and III
(B) III and IV
(C) II only
(D) IV only

NODIA

2018

76. The narrow region of soil immediately surrounding and influenced by plant roots and their exudates is called the:
(A) Bulk soil
(B) Rhizosphere
(C) Detritusphere
(D) Phyllosphere

2025

77. Plant roots often release organic acids (like citrate and malate) into the rhizosphere primarily to:
(A) Solubilize phosphorus and complex toxic aluminum.
(B) Exert a toxic effect on neighboring weed roots.
(C) Significantly increase pH in alkaline soil types.
(D) Synthesize the structure of primary cell walls.

2007

78. Siderophores are low-molecular-weight compounds secreted in the rhizosphere by microbes and certain plants (phytosiderophores) specifically to chelate and facilitate the uptake of:
(A) Manganese
(B) Zinc
(C) Iron
(D) Copper

2006

79. In Strategy I plants (dicots and non-graminaceous monocots), iron acquisition from the rhizosphere involves:
(A) The metabolic release of various

(A) Total crop biomass / Total transpiration.
(B) (Yield change) / (Amount of fertilizer applied).
(C) Nutrient in grain / Nutrient in the shoot.
(D) (Yield level) / (Amount of fertilizer used).

2024

102. Physiological Nutrient Use Efficiency primarily reflects:
(A) The efficiency of root architecture in mining the soil
(B) The fraction of applied fertilizer recovered in the harvested plant parts
(C) The ability of the plant to convert absorbed nutrients into economic yield
(D) The rate of foliar nutrient penetration

2019

103. The Mitscherlich yield equation is based on the principle that:
(A) Total yield is determined by the soil texture.
(B) Yield increase is proportional to decrement from max.
(C) Yield rises exponentially with unlimited nutrient.
(D) Toxicity occurs after the critical concentration.

2022

104. The Nitrogen Harvest Index (NHI) is calculated as:
(A) Nitrogen in the grain / Total above-ground plant nitrogen
(B) Total nitrogen in the plant / Soil available nitrogen
(C) Grain weight / Total nitrogen applied
(D) Vegetative nitrogen / Grain nitrogen

2022

105. Consider the following statements on Nutrient Use Efficiency (NUE):
I. High apparent recovery efficiency always guarantees high agronomic efficiency.
II. Internal utilization efficiency is defined as grain yield divided by total nutrient uptake.
III. Precision farming tools like SPAD meters help improve nitrogen use efficiency.
Which of the following represents the correct combination of statements?
(A) II and III
(B) I and II
(C) I and III
(D) III only

2007

106. At the molecular level, plants can improve Phosphorus Use Efficiency (PUE) under deficiency by upregulating the expression of which transcription factor family?
(A) PHR1 (Phosphate Starvation Response 1)
(B) WRKY75 (Phosphate-responsive transcription factor)
(C) ABI3
(D) MYB10

2022

107. Transgenic approaches to improve NUE often target the overexpression of:
(A) Lignin biosynthetic enzymes to increase root mass
(B) Proteases in the senescing leaves to prevent nutrient remobilization
(C) High-affinity root transporter genes like NRT2
(D) Enzymes of the photorespiratory pathway

2014

108. Autophagy plays a critical role in enhancing plant NUE by:
(A) Consistently decreasing the rate of root proliferation.
(B) Increasing stomatal closure to retain cellular water.
(C) Remobilizing macromolecules from old leaves to sinks.
(D) Enhancing the initial uptake of nitrate from the soil.

2022

109. Heavy metals like Cadmium (Cd) primarily cause cellular toxicity in plants by:
(A) Uncoupling photophosphorylation in the dark
(B) Stimulating overproduction of chlorophyll
(C) Increasing the turgor pressure of epidermal cells leading to bursting
(D) Inducing oxidative stress and displacing essential metals from metalloproteins

2017

110. Phytochelatins are enzymatically synthesized peptides crucial for heavy metal detoxification. They are polymerized from which precursor molecule?
(A) Ascorbate
(B) Glutathione
(C) Proline
(D) Methionine

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(D) Calmodulin

2008

90. The initiation of legume nodulation begins with the plant root secreting specific signaling molecules, predominantly:
(A) Auxins
(B) Gibberellins
(C) Strigolactones
(D) Flavonoids

2015

91. The first step of nitrate assimilation in plants, reducing nitrate to nitrite, is catalyzed by nitrate reductase. Where is this enzyme primarily located?
(A) Cytosol
(B) Mitochondria
(C) Chloroplast stroma
(D) Peroxisomes

2025

92. Nitrate reductase utilizes which specific trace element as a central structural component of its pterin cofactor?
(A) Nickel
(B) Copper
(C) Zinc
(D) Molybdenum

2002

93. The primary pathway for the assimilation of ammonium into organic molecules in higher plants is the:
(A) GDH (Glutamate dehydrogenase) pathway
(B) GS-GOGAT pathway
(C) Shikimate pathway
(D) TCA cycle

2019

94. Which statement regarding nitrite reductase is INCORRECT?
(A) It is located in the cytosol of leaf cells.
(B) It reduces nitrite to ammonium.
(C) In leaves, it utilizes reduced ferredoxin from the light reactions.
(D) It prevents the accumulation of toxic nitrite.

2009

95. Match the enzymes in List I with the subcellular locations in List II.
List I: (Enzyme)
P. Nitrate Reductase
Q. Nitrite Reductase (leaf)
R. Glutamine Synthetase (GS2)
S. Nitrogenase
List II: (Subcellular Location)
1. Chloroplast
2. Cytosol
3. Bacteroid
4. Plastid/Chloroplast
(A) P-2, Q-1, R-4, S-3
(B) P-2, Q-3, R-1, S-4
(C) P-1, Q-2, R-4, S-3
(D) P-3, Q-2, R-1, S-4

NODIA

2008

96. Before sulfate can be reduced and assimilated into amino acids in plants, it must first be activated. This activation step forms:
(A) Hydrogen sulfide (H2S)
(B) Sulfite (SO_3^{2-})
(C) Cysteine
(D) Adenosine 5'-phosphosulfate (APS)

2015

97. The activation of sulfate to APS is catalyzed by which enzyme?
(A) APS reductase
(B) Sulfite reductase
(C) ATP sulfurylase
(D) O-acetylserine (thiol) lyase

2014

98. The first stable organic compound formed during the primary assimilation of sulfur in plants is:
(A) Methionine
(B) Cysteine
(C) Glutathione
(D) Homocysteine

2012

99. In addition to being a precursor for methionine, cysteine is essential for the biosynthesis of which major cellular antioxidant?
(A) Ascorbic acid
(B) Alpha-tocopherol
(C) Glutathione
(D) Proline

2013

100. Which group of plants typically has the highest sulfur requirement due to the synthesis of glucosinolates?
(A) Crucifers (Brassicaceae)
(B) Legumes (Fabaceae)
(C) Grasses (Poaceae)
(D) Nightshades (Solanaceae)

2016

101. Agronomic Nutrient Use Efficiency (NUE) is typically defined mathematically as:

phytosiderophores.
(B) Substitution via symbiotic mycorrhizal associations.
(C) The direct endocytosis of ferric oxide molecules.
(D) Proton extrusion and reduction of Fe^{3+} to Fe^{2+}.

2019

80. Unlike Strategy I plants, Strategy II plants (grasses) acquire iron by:
(A) Depending entirely on iron solubilizing soil bacteria.
(B) Secreting phytosiderophores that complex Fe3+.
(C) Acidifying the rhizosphere via plasma H-ATPases.
(D) Relying exclusively on foliar nutrient absorption.

2015

81. Arbuscular Mycorrhizal Fungi (AMF) primarily enhance plant acquisition of which notoriously immobile soil nutrient?
(A) Nitrate
(B) Phosphorus
(C) Chloride
(D) Calcium

2005

82. The characteristic branching hyphal structures formed inside root cortical cells by AMF, serving as major sites for nutrient exchange, are called:
(A) Arbuscules
(B) Vesicles
(C) Ectomycorrhizal mantles
(D) Hartig nets

2001

83. Phosphorus-solubilizing bacteria (PSB) in the rhizosphere increase phosphorus availability primarily by:
(A) Fixing atmospheric nitrogen
(B) Secreting siderophores
(C) Enhancing stomatal conductance
(D) Producing organic acids and acid phosphatases

2006

84. Plant Growth-Promoting Rhizobacteria (PGPR) can enhance plant nutrient status through which mechanism?
(A) Producing phytohormones like IAA to stimulate root system development
(B) Producing antibiotics to inhibit plant roots
(C) Sequestering all available soil nitrogen into their own biomass
(D) Decreasing root surface area

2001

85. For the following question, choose the correct option from (A), (B), (C), and (D) based on the Assertion (A) and Reason (R) provided.
Assertion (A): Ectomycorrhizal associations are characterized by the presence of a Hartig net and a fungal mantle around the root tip.
Reason (R): Ectomycorrhizal fungi do not generally penetrate the plasma membrane of root cortical cells, preferring to grow between the cells.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2011

86. The enzyme complex exclusively responsible for Biological Nitrogen Fixation (BNF) is:
(A) Nitrogenase
(B) Nitrate reductase
(C) Glutamine synthetase
(D) Urease

2012

87. The nitrogenase enzyme complex consists of two primary protein components:
(A) Fe-protein (reductase) and MoFe-protein (dinitrogenase).
(B) Ferredoxin and the copper-containing plastocyanin.
(C) Cytochrome f and the membrane-bound ATP synthase.
(D) Rubisco and the primary PEP carboxylase enzyme.

2013

88. Nitrogenase is highly sensitive to and rapidly inactivated by:
(A) Carbon dioxide
(B) Argon
(C) Oxygen
(D) Hydrogen gas

2004

89. In legume root nodules, the oxygen concentration is kept low yet sufficient for bacteroid respiration by the action of an oxygen-binding protein called:
(A) Cytochrome oxidase
(B) Phytoferritin
(C) Leghemoglobin

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2001

111. The enzyme responsible for synthesizing metal-binding peptides from glutathione in response to heavy metal exposure is:
(A) Glutathione reductase
(B) Phytochelatin synthase
(C) APS reductase
(D) ATP sulfurylase

2015

112. Unlike phytochelatins, metallothioneins are:
(A) Short, enzymatically synthesized carbohydrates
(B) Gene-encoded, cysteine-rich, low-molecular-weight proteins
(C) Extracellular chelators secreted into the rhizosphere
(D) Present exclusively in hyperaccumulator roots

2016

113. The phytoremediation strategy involving the use of plants to absorb, translocate, and concentrate toxic heavy metals in their harvestable shoot tissue is known as:
(A) Phytostabilization
(B) Phytovolatilization
(C) Phytoextraction
(D) Phytodegradation

2002

114. Phytovolatilization is specifically useful for the remediation of which of the following elements, as they can be transformed into less toxic, gaseous forms?
(A) Lead and Cadmium
(B) Selenium and Mercury
(C) Zinc and Iron
(D) Chromium and Nickel

2003

115. Consider the following statements regarding hyperaccumulator plants:
I. They tolerate high concentrations of metals without showing toxicity symptoms.
II. They typically restrict metal accumulation exclusively to root tissues.
III. They actively translocate heavy metals to shoot vacuoles.
IV. Thlaspi caerulescens is a well-known hyperaccumulator of zinc and cadmium.
Which of the following represents the INCORRECT combination of statements?
(A) I and III
(B) III and IV
(C) II only
(D) I only

2021

116. Which of the following beneficial elements is essential for the synthesis of Vitamin B12 (cobalamin) by symbiotic nitrogen-fixing bacteria?
(A) Sodium
(B) Silicon
(C) Cobalt
(D) Selenium

2015

117. If an element is found in high concentrations within a plant but experimental removal of this element shows no adverse effects on growth, reproduction, or metabolism, the element is:
(A) A non-essential element taken up via luxury consumption or passive influx.
(B) An essential micronutrient.
(C) A structural macronutrient.
(D) A beneficial element acting under stress.

2022

118. The elements Carbon, Hydrogen, and Oxygen constitute approximately what percentage of a plant's total dry matter?
(A) 15-20%
(B) 45-50%
(C) 70-80%
(D) 90-95%

NODIA

2018

119. Which of the following differentiates macronutrients from micronutrients?
(A) Macronutrients are only needed for vegetative growth.
(B) Micronutrients do not participate in enzyme systems.
(C) Concentration in tissue exceeds 10 mmol/kg dry weight.
(D) Micronutrients are synthesized rather than absorbed.

2002

120. In a saline environment, the application of which beneficial element has been shown to reduce sodium toxicity in certain plants by competing for uptake sites or improving tissue tolerance?
(A) Cobalt
(B) Nickel
(C) Silicon
(D) Selenium

(D) Transcellular pathway

2011

59. In the root cortex, the predominant pathway for the passive radial diffusion of ions prior to reaching the endodermis is the:
(A) Apoplastic pathway
(B) Vacuolar pathway
(C) Phloem loading pathway
(D) Transpirational bypass

2025

60. What structural feature prevents the leakage of ions back into the soil from the stele after they have been actively loaded into the root xylem?
(A) Cortex
(B) Endodermis
(C) Epidermis
(D) Root cap

2013

61. The Casparian strip is predominantly composed of:
(A) Pectin and hemicellulose
(B) Suberin and lignin
(C) Chitin and peptidoglycan
(D) Cutin and wax

2009

62. The presence of the Casparian strip forces apoplastic ions to enter the stele by:
(A) Crossing a plasma membrane to enter the symplast.
(B) Diffusing through the large intercellular air spaces.
(C) Traveling backwards to the epidermal root hair cells.
(D) Bypassing the endodermis through specialized hydathodes.

2023

63. Which specialized endodermal cells lack prominent Casparian thickenings, allowing continued symplastic radial transport into the stele in older root zones?
(A) Guard cells
(B) Bulliform cells
(C) Passage cells
(D) Trichoblasts

2016

64. Xylem loading of ions in the root stele is primarily mediated by transport proteins located on the plasma membrane of:
(A) Epidermal cells
(B) Cortical cells
(C) Root cap cells
(D) Xylem parenchyma cells

2024

65. Consider the following statements regarding xylem loading in roots:
I. SKOR is an outward-rectifying K^+ channel responsible for loading potassium into the xylem.
II. Xylem loading is a strictly passive process that never requires energy or transport proteins.
III. Xylem parenchyma cells actively transport ions into dead tracheary elements.
Which of the following represents the correct combination of statements?
(A) I and III
(B) II and III
(C) I and II
(D) I only

2003

66. The bulk movement of ions from roots to shoots through the xylem is predominantly driven by:
(A) Cytoplasmic streaming
(B) Transpiration stream
(C) Phloem pressure flow
(D) ATP-dependent motor proteins

2007

67. In contrast to the xylem, transport of nutrients in the phloem is:
(A) Strictly unidirectional in an upward direction.
(B) Driven solely by the force of root pressure.
(C) Mediated through the lumen of dead plant cells.
(D) Bidirectional, moving from sources to sinks.

2006

68. Which of the following nutrients is considered highly immobile in the plant phloem, meaning its deficiency symptoms first appear on young leaves?
(A) Calcium
(B) Nitrogen
(C) Phosphorus
(D) Potassium

2001

69. Which of the following statements about long-distance transport is INCORRECT?
(A) Nitrogen can be transported in the xylem as nitrate or amino acids.
(B) Xylem unloading is required for leaf cells to utilize xylem-borne nutrients.

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2016

132. Calcareous soils (high pH, high calcium carbonate) characteristically induce deficiencies in which group of nutrients?
(A) N, K, and S
(B) Ca, Mg, and Mo
(C) P, B, and Cl
(D) Fe, Mn, Zn, and Cu

2021

133. Why does phosphorus availability peak sharply around a soil pH of 6.5?
(A) Below 6.5 it leaches rapidly; above 6.5 it is consumed by microbes.
(B) It is the optimal pH for mycorrhizal survival.
(C) Below 6.5 it precipitates with Fe and Al; above 6.5 it precipitates with Ca.
(D) At pH 6.5, phosphorus is converted to volatile phosphine gas.

2012

134. The excessive application of phosphorus fertilizers can induce a deficiency of which micronutrient due to the formation of insoluble phosphates in the soil or root?
(A) Molybdenum
(B) Zinc
(C) Boron
(D) Chlorine

2019

135. Match the spaces or pathways in List I with the characteristics in List II.
List I: (Space/Pathway)
P. Water Free Space
Q. Donnan Free Space
R. Symplast
S. Apoplast
List II: (Characteristic)
1. Readily exchangeable ions in intercellular spaces
2. Continuous living cytoplasm interconnected by plasmodesmata
3. Space containing fixed non-diffusible negative charges
4. Extracellular continuum of cell walls
(A) P-1, Q-3, R-2, S-4
(B) P-2, Q-3, R-1, S-4
(C) P-3, Q-1, R-4, S-2
(D) P-1, Q-4, R-2, S-3

2008

136. In the Donnan Free Space, the presence of fixed negative charges causes the concentration of mobile cations to be:
(A) Zero
(B) Equal to the external solution
(C) Higher than the external solution
(D) Lower than the external solution

2013

137. The equation $\Delta\mu_j = RT\ln\left(\frac{C_i}{C_o}\right) + zF\Delta E$ calculates the:
(A) Rate of diffusion according to Fick's Law
(B) Electrochemical potential difference for ion j
(C) Half-velocity constant (Km) of the transporter
(D) Water potential of the cell

NODIA

2007

138. If the electrochemical potential difference ($\Delta\mu$) for an ion across a membrane is zero, it implies that:
(A) The ion is actively being pumped out.
(B) The ion is at thermodynamic equilibrium across the membrane.
(C) The membrane has ruptured.
(D) There are no transport proteins available for this ion.

2017

139. Aquaporins are specialized channel proteins that primarily facilitate the rapid movement of water, but some isoforms can also transport uncharged molecules such as:
(A) Nitrate and sulfate
(B) ATP and ADP
(C) Urea and boric acid
(D) Large proteins and RNA

2024

140. Which of the following is an INCORRECT statement regarding ABC (ATP-Binding Cassette) transporters in plants?
(A) They are primary active transporters.
(B) They couple transport directly to ATP hydrolysis.
(C) They exclusively transport protons to generate the membrane potential.
(D) They are involved in the vacuolar sequestration of phytochelatin-heavy metal complexes.

2015

141. In root ion uptake, an external concentration of nitrate at 0.05 mM would likely be taken up primarily by:
(A) The High-Affinity Transport System (HATS)
(B) The Low-Affinity Transport System (LATS)
(C) Simple diffusion across the lipid bilayer
(D) Endocytosis

2016

142. The expression of high-affinity nitrate transporter (NRT2) genes in plant roots is typically:
(A) Constitutive and unregulated
(B) Strongly upregulated under nitrogen starvation
(C) Only induced under high external nitrate concentrations (>10 mM)
(D) Suppressed by light

2010

143. The resistance to water and solute flow in the root symplastic pathway is primarily governed by the frequency and conductance of:
(A) Plasmodesmata
(B) Casparian strips
(C) Aquaporins
(D) Xylem pits

2022

144. In a transcellular pathway, unlike the purely symplastic pathway, water and solutes must cross the:
(A) Cuticle
(B) Lignified secondary wall exclusively
(C) Plasma membranes of the same cell twice (entering and exiting)
(D) Plasmodesmata without entering the cytoplasm

2017

145. Consider the following statements regarding radial transport and the endodermis:
I. The Casparian strip blocks the apoplastic pathway.
II. Passage cells remain un-suberized in older roots to allow transport.
III. The endodermis prevents the leakage of actively loaded ions from the stele.
IV. Suberin strictly allows the free diffusion of water.
V. The xodermis, when present, can form a second Casparian band.
Which of the above statement(s) is/are correct?
(A) I, II, III, and V
(B) I, III, IV, and V
(C) II, III, and IV
(D) I, II, and IV

2013

146. Root pressure, which can lead to guttation, is osmotic in nature and builds up directly due to:
(A) Active accumulation of ions in the xylem sap of the stele
(B) Rapid transpiration
(C) High soil tension
(D) Photosynthesis in the root cortex

2015

147. When planning a fertilization strategy, knowing that Calcium is phloem-immobile means that:
(A) Single planting application supports all future fruit growth.
(B) Calcium moves easily from older leaves to the growing fruits.
(C) Deficiency symptoms will appear first on the oldest leaves.
(D) Requires continuous soil supply or repeated foliar sprays.

2023

148. Xylem unloading into expanding sink leaves occurs predominantly via:
(A) Active transport of solute molecules into the phloem.
(B) Apoplastic diffusion from tracheids then mesophyll uptake.
(C) Simple evaporation through the leaf stomatal pores.
(D) Mass flow of water directly into the cell vacuole.

2021

149. The Point of Deliquescence (POD) of a foliar fertilizer salt refers to:
(A) Specific pH level where the nutrient is easily absorbed.
(B) Temperature at which the fertilizer salt breaks down.
(C) Humidity level where salt absorbs water to become liquid.
(D) Concentration at which the salt scorches the leaf surface.

2018

150. The addition of urea to a foliar iron spray often increases iron uptake because:
(A) Urea facilitates cuticular penetration by increasing the permeability of the cuticle.
(B) Urea alters the pH of the apoplast to 2.0.
(C) Urea crystallizes and breaks open the epidermal cells.
(D) Urea acts as a strong chelator for iron.

2004

151. The rhizosphere pH can be significantly altered depending on the form of nitrogen supplied. Uptake of nitrate (NO_3^-) generally causes the rhizosphere to:
(A) Become more alkaline due to OH^- or HCO_3^- efflux
(B) Become more acidic due to H^+ efflux

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(C) Produce massive amounts of CO_2
(D) Remain completely unchanged

2016

152. Mucilage produced by the root cap plays several roles in the rhizosphere. Which of the following is NOT a recognized function of root mucilage?
(A) Lubricating the root tip through the soil
(B) Protecting the root from desiccation
(C) Actively fixing atmospheric nitrogen gas
(D) Binding heavy metals to prevent their uptake

2022

153. The primary form of phosphorus absorbed by plant roots, the availability of which is strongly enhanced by AMF, is:
(A) Orthophosphate ($H_2PO_4^-$ / HPO_4^{2-})
(B) Polyphosphate
(C) Phosphite (HPO_3^{2-})
(D) Phytate

2016

154. In addition to improved phosphorus nutrition, AMF colonization frequently confers which additional benefit to the host plant?
(A) Complete immunity to all viral diseases
(B) Enhanced tolerance to drought and root pathogens
(C) The ability to grow without sunlight
(D) The capacity to perform biological nitrogen fixation

2013

155. In the biological nitrogen fixation equation, how many moles of ATP are minimally required for the reduction of one mole of N_2 to two moles of NH_3?
(A) 2
(B) 8
(C) 16
(D) 32

2025

156. Hydrogen gas (H_2) is obligatorily produced during nitrogen fixation. Some highly efficient rhizobia possess which enzyme to recycle this hydrogen and recover energy?
(A) Hydrogen peroxide dismutase
(B) Nitrogenase reductase
(C) Uptake hydrogenase (Hup)
(D) Cytochrome P450

2003

157. Accumulation of nitrite in plant cells is highly toxic. Therefore, the activity of nitrite reductase in the chloroplast is typically:
(A) Much lower than that of nitrate reductase
(B) Unregulated and spontaneous
(C) Much higher than that of nitrate reductase
(D) Dependent on dark conditions

2002

158. In the GS-GOGAT pathway, Glutamine Synthetase (GS) catalyzes the ATP-dependent amination of:
(A) Alpha-ketoglutarate to form glutamate
(B) Glutamate to form glutamine
(C) Aspartate to form asparagine
(D) Pyruvate to form alanine

2016

159. GOGAT (Glutamine-2-oxoglutarate aminotransferase) transfers the amide group from glutamine to alpha-ketoglutarate to produce:
(A) Two molecules of glutamine
(B) One molecule of urea
(C) Two molecules of glutamate
(D) One molecule of oxaloacetate

2023

160. The reduction of APS to sulfite, and subsequently to sulfide during sulfur assimilation, predominantly occurs in the:
(A) Mitochondria
(B) Cytosol
(C) Endoplasmic reticulum
(D) Chloroplasts/Plastids

2021

161. Sulfur deficiency symptoms often manifest first on younger leaves as generalized chlorosis because:
(A) Sulfur is volatile and evaporates from young leaves.
(B) Sulfur is highly mobile and moves to the older leaves.
(C) Sulfur is relatively immobile within the plant.
(D) Young leaves lack the enzyme ATP sulfurylase.

2014

162. A low Physiological Nutrient Use Efficiency paired with a high Nutrient Uptake Efficiency indicates that the crop:
(A) Root system cannot absorb the fertilizer from the soil.
(B) The soil environment experiences severe leaching loss.
(C) Plant has already reached the maximum possible yield.
(D) Absorbs nutrient well but fails to convert it

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to yield.

2018

163. The Recovery Efficiency of applied nitrogen fertilizer rarely exceeds 50% in standard agricultural systems. The remainder is lost primarily through:
(A) Transpiration and guttation
(B) Leaching, denitrification, and volatilization
(C) Sequestration in the seed
(D) Photodegradation

2025

164. Overexpressing the cytosolic glutamine synthetase (GS1) gene in transgenic plants has been a major target to improve:
(A) Phosphorus acquisition
(B) Salinity tolerance
(C) Nitrogen remobilization and Use Efficiency
(D) Heavy metal detoxification

2001

165. For the following question, choose the correct option from (A), (B), (C), and (D) based on the Assertion (A) and Reason (R) provided.
Assertion (A): Increasing the expression of specific nitrate transporters (like NRT1.1) can enhance the total nitrogen uptake of the plant.
Reason (R): NRT1.1 is a dual-affinity nitrate transporter that helps roots acquire nitrate across a wide range of external concentrations.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2024

166. Some plants naturally hyperaccumulate heavy metals without suffering toxicity. A key cellular mechanism enabling this is the sequestration of metal ions into the:
(A) Nucleus
(B) Chloroplast thylakoid lumen
(C) Vacuole
(D) Mitochondria

2019

167. Arsenic (As) toxicity in plants is often exacerbated because arsenate is a chemical analogue of, and competes for the transport mechanisms of:
(A) Nitrate
(B) Phosphate
(C) Sulfate
(D) Chloride

2022

168. The use of deep-rooted trees, like poplar and willow, to take up contaminated groundwater and transpire it while leaving or degrading the contaminants is a form of:
(A) Phytoextraction
(B) Phytomining
(C) Phytovolatilization / Hydraulic control
(D) Phytostimulation

2010

169. A true metal hyperaccumulator plant is typically defined by its ability to accumulate target metals in its dried shoot tissue at concentrations greater than:
(A) 0.1% to 1% (e.g., >1000 mg/kg for Ni, >10,000 mg/kg for Zn)
(B) 10-50 mg/kg
(C) 1-5 mg/kg
(D) 0.01 mg/kg

NODIA

2012

170. Julius von Sachs pioneered the methodology for identifying essential nutrients by growing plants in defined mineral solutions without soil. This technique is known as:
(A) Aeroponics
(B) Hydroponics (solution culture)
(C) Tissue culture
(D) Soil bioassay

2012

171. Which essential macronutrient is absorbed by plants as a monovalent cation?
(A) Calcium
(B) Potassium
(C) Magnesium
(D) Sulfur

2006

172. The transition zone on a nutrient response curve between the "hidden hunger" phase and the "luxury consumption" phase is marked by the:
(A) Toxicity limit
(B) Deficient zone
(C) Critical nutrient concentration
(D) Minimum required concentration

2014

173. Calcium deficiency is detrimental to meristematic growth because calcium is required for:
(A) Spindle fiber formation and cell division
(B) Electron transport in photosystem I
(C) The synthesis of gibberellic acid
(D) Stomatal opening

2006

174. Boron is unique among essential micronutrients because it is taken up by roots from the soil solution predominantly as:
(A) A chelated organic complex
(B) A polyatomic anion (BO_3^{3-})
(C) A divalent cation (B^{2+})
(D) Undissociated boric acid (H_3BO_3)

2004

175. Match the nutrients in List I with the specific deficiency symptoms in List II.
List I: (Nutrient)
P. Iron
Q. Zinc
R. Molybdenum
S. Calcium
List II: (Specific Deficiency Symptom)
1. Whiptail of cauliflower
2. Blossom-end rot of tomato
3. Interveinal chlorosis on young leaves
4. Little leaf and shortened internodes
(A) P-3, Q-4, R-1, S-2
(B) P-4, Q-2, R-1, S-3
(C) P-3, Q-1, R-4, S-2
(D) P-1, Q-4, R-3, S-2

2010

176. The practice of liming acidic soils primarily aims to improve plant growth by:
(A) Increasing the solubility of both iron and manganese.
(B) Enhancing the volatilization of soil-bound ammonia.
(C) Decreasing the base saturation of the soil complex.
(D) Reducing aluminum toxicity while increasing phosphorus.

2016

177. An ion diffusing into the Donnan Free Space is subject to the Donnan equilibrium, which dictates that:
(A) Inside cation-anion product equals outside product.
(B) All ions are completely excluded from the local space.
(C) Only anions can enter into the specified tissue space.
(D) The space actively pumps ions into the cell cytoplasm.

2013

178. The plasma membrane H^+-ATPase is activated by which plant hormone to initiate cell wall loosening and elongation?
(A) Abscisic acid
(B) Auxin
(C) Ethylene
(D) Cytokinin

2005

179. Ion channels in plant membranes can be regulated (gated) by various signals. Channels that open or close in response to changes in the membrane potential are termed:
(A) Mechanosensitive channels
(B) Ligand-gated channels
(C) Voltage-gated channels
(D) Light-gated channels

2017

180. In the context of the Michaelis-Menten kinetics for ion uptake, a competitive inhibitor (like arsenate competing with phosphate) will:
(A) Decrease the $V_{\{}\max_{\}}$ without changing the K_m
(B) Increase the apparent K_m without changing the $V_{\{}\max_{\}}$
(C) Decrease both $V_{\{}\max_{\}}$ and K_m
(D) Uncompetitively block the channel pore

2007

181. Plasmodesmata are lined by the plasma membrane and contain a central tubular structure derived from the endoplasmic reticulum called the:
(A) Desmotubule
(B) Tonoplast
(C) Phragmoplast
(D) Middle lamella

2018

182. The active loading of solutes into the root xylem elements primarily relies on transport proteins driven by the electrochemical gradient generated by:
(A) H^+-ATPases located in the plasma membrane of adjacent xylem parenchyma cells
(B) Mitochondria within the dead tracheary elements
(C) Companion cells of the phloem
(D) Guard cells in the root epidermis

2019

183. The rapid, long-distance movement of phloem sap from sources to sinks is best explained by the:
(A) Cohesion-tension theory
(B) Root pressure mechanism
(C) Pressure-flow hypothesis (Münch hypothesis)
(D) Capillary action

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10 millimolar.

2025

205. Select the correct order of tissues an ion must traverse when moving from the soil solution to the root xylem via the symplastic pathway:
(A) Cortex → Epidermis → Pericycle → Endodermis → Xylem
(B) Epidermis → Cortex → Endodermis → Pericycle → Xylem
(C) Epidermis → Endodermis → Cortex → Pericycle → Xylem
(D) Endodermis → Cortex → Epidermis → Pericycle → Xylem

2021

206. In the root, the pericycle is located:
(A) Outside the endodermis
(B) Immediately inside the endodermis
(C) Between the epidermis and the cortex
(D) Within the pith

2006

207. Xylem transport is highly sensitive to cavitation (formation of air embolisms). Plants overcome small cavitations in the xylem primarily by:
(A) Reversing the transpiration stream
(B) Rapidly synthesizing new xylem elements overnight
(C) Relying on root pressure to refill embolized vessels at night
(D) Opening all stomata to flush out the air

2021

208. Which physical property of a foliar applied nutrient solution is modified by adding a surfactant to improve leaf wetting and uptake?
(A) Boiling point
(B) Osmotic potential
(C) Surface tension
(D) Cation exchange capacity

2019

209. In response to aluminum toxicity in acidic soils, many resistant plant species (like wheat and maize) secrete which specific organic anions from their root apices to chelate the aluminum?
(A) Malate and citrate
(B) Acetate and formate
(C) Ascorbate and glutathione
(D) Urate and allantoin

2024

210. Arrange the following events in the establishment of Arbuscular Mycorrhizal symbiosis in the correct sequence:
I. Root penetration by the hyphopodium
II. Secretion of strigolactones by the host root
III. Formation of highly branched arbuscules in cortical cells
IV. Spore germination and hyphal branching
Select the correct arrangement:
(A) II, I, IV, III
(B) II, IV, I, III
(C) IV, II, I, III
(D) I, II, III, IV

2015

211. A massive application of synthetic nitrogen fertilizer to a legume field will generally cause the plant to:
(A) Increase nitrogen fixation proportionally
(B) Downregulate nitrogenase activity and rely on the soil nitrogen
(C) Develop significantly more and larger nodules
(D) Synthesize toxic levels of nitrate

2019

212. Glutamate dehydrogenase (GDH) can assimilate ammonium, but in higher plants, its primary physiological role is more likely related to:
(A) Primary ammonium assimilation from the soil
(B) Direct reduction of nitrate
(C) Deamination of glutamate during carbon starvation or senescence
(D) Photosynthetic carbon fixation

2001

213. The sulfur-containing tripeptide glutathione is critical for protecting the plant against:
(A) Reactive oxygen species (ROS) and heavy metals
(B) Herbivore chewing damage
(C) Viral replication
(D) Extreme cold temperatures

NODIA

2011

214. SPAD chlorophyll meters are extensively used in precision agriculture to rapidly assess the real-time status of which essential nutrient?
(A) Phosphorus
(B) Nitrogen
(C) Potassium
(D) Calcium

2002

215. Select the correct sequence of steps involved in nitrate sensing and assimilation in plant roots:
(A) Nitrate reduction → Transceptor sensing → Uptake via NRT → Amino acid synthesis

2001

194. Arnon and Stout established the criteria of essentiality based on experiments primarily utilizing which plant species?
(A) Arabidopsis thaliana
(B) Tomato (Lycopersicon esculentum)
(C) Wheat (Triticum aestivum)
(D) Rice (Oryza sativa)

2003

195. Which element is generally classified as a micronutrient but is required in significantly higher quantities by legumes engaged in active biological nitrogen fixation?
(A) Zinc
(B) Copper
(C) Molybdenum
(D) Chlorine

2015

196. In diagnosing nutrient status, tissue analysis is preferred over soil testing for identifying hidden hunger because:
(A) Soil tests are unable to detect most macronutrients.
(B) Directly reflects nutrient absorption and assimilation.
(C) Tissue analysis is cheaper than soil testing costs.
(D) Soil pH makes soil testing irrelevant for nutrition.

2003

197. A high concentration of potassium in the soil solution can antagonistically suppress the uptake of which two important macronutrients?
(A) Nitrogen and Phosphorus
(B) Sulfur and Carbon
(C) Calcium and Magnesium
(D) Iron and Zinc

2019

198. Boron is particularly critical during the reproductive stage of plants because it is intimately involved in:
(A) Pollen tube elongation and germination
(B) ATP synthesis in the seed
(C) Nodule formation on pods
(D) Ethylene synthesis for fruit ripening

2011

199. Interveinal chlorosis on older leaves is a hallmark symptom of magnesium deficiency. This specific pattern occurs because:
(A) The element is highly immobile in the phloem sap.
(B) The element is remobilized from older leaves to support new growth.
(C) It is rapidly excreted by root systems into soil.
(D) It is deactivated by high intensities of sunlight.

2008

200. In waterlogged or anaerobic soil conditions, nitrate (NO_3^-) is rapidly lost from the soil profile primarily through the microbial process of:
(A) Nitrification
(B) Ammonification
(C) Denitrification
(D) Nitrogen fixation

2021

201. The rapid, initial phase of ion uptake when a root is placed in a salt solution is primarily due to:
(A) Active transport across the tonoplast
(B) Passive diffusion into the Apparent Free Space (AFS)
(C) Symplastic loading into the xylem
(D) Synthesis of new carrier proteins

2023

202. The secondary active transport of sucrose into the phloem companion cells is driven by a symporter that couples sucrose movement with the influx of:
(A) Protons (H^+)
(B) Potassium ions
(C) Calcium ions
(D) Sodium ions

2005

203. K^+ inwardly rectifying channels (KIRCs) in guard cells open to allow potassium influx, a critical event that leads to:
(A) Stomatal closure
(B) ABA production
(C) Guard cell swelling and stomatal opening
(D) Immediate loss of turgor

2002

204. The dual-isotherm of potassium uptake in roots demonstrates that the High-Affinity Transport System (HATS):
(A) Functions always as a passive ion channel in the root.
(B) Is localized strictly within the root cap tissue cells.
(C) Operates against gradients and requires metabolic energy.
(D) Activates only when external levels exceed

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(C) I, IV, and V
(D) II, IV, and V

2008

226. The energy stored in the transmembrane proton gradient (proton motive force) is used directly to drive:
(A) Primary active transport
(B) Simple diffusion
(C) Aquaporin opening
(D) Secondary active transport and ATP synthesis (in organelles)

2014

227. Carrier proteins exhibit kinetics similar to enzymes, including a maximal transport rate, because they:
(A) Are continuously degraded within the plasma membrane.
(B) Form permanent open pores across the entire bilayer.
(C) Must undergo time-consuming conformational changes.
(D) Rely on the speed of light for ionic translocation.

2023

228. When evaluating root uptake kinetics under nutrient deficiency, plants generally attempt to compensate by:
(A) Decreasing the total number of membrane transporters.
(B) Increasing affinity (low Km) or transporter density.
(C) Closing all leaf stomata to reduce the water uptake.
(D) Shedding older roots to conserve metabolic resources.

2016

229. The continuous apoplastic pathway in the root is physically interrupted by the Casparian strip located in the:
(A) Endodermis
(B) Exodermis
(C) Pericycle
(D) Epidermis

2016

230. After passing the endodermis via the symplast, nutrients enter the dead xylem vessels (which lack cytoplasm). This crucial efflux step from the xylem parenchyma into the tracheary elements is known as:
(A) Xylem loading
(B) Phloem unloading
(C) Guttation
(D) Cavitation

****

NODIA

(B) Transceptor sensing → Nitrate reduction → Uptake via NRT → Amino acid synthesis
(C) Transceptor sensing (e.g., NRT1.1) → Uptake via NRT → Nitrate reduction → Amino acid synthesis
(D) Uptake via NRT → Amino acid synthesis → Transceptor sensing → Nitrate reduction

2007

216. Arsenic tolerance in certain plants, like the fern Pteris vittata, is achieved by rapid uptake of arsenate, its reduction to arsenite, and subsequent storage in the:
(A) Cell wall apoplast
(B) Chloroplasts
(C) Vacuoles of the leaf fronds
(D) Mitochondria

2023

217. Which plant characteristic is NOT typically advantageous for a species chosen for phytoextraction?
(A) Extremely slow growth rate and low biomass production
(B) Extensive root system
(C) High tolerance to the target metal
(D) Ability to translocate metals from root to shoot

2017

218. According to the criteria of essentiality, an element is essential if it is a component of an essential molecule in the plant. Which of the following best exemplifies this?
(A) Silicon in the cell wall
(B) Sodium in the vacuole
(C) Aluminum in the cortex
(D) Magnesium in the chlorophyll molecule

2005

219. Which of the following sets of elements are categorized as structural elements, forming the bulk of plant dry matter?
(A) N, P, K
(B) C, H, O
(C) Ca, Mg, S
(D) Fe, Mn, Zn

2004

220. Arrange the following phases of a plant's growth response curve to an increasing concentration of a nutrient in the correct sequence:
I. Luxury consumption
II. Toxicity
III. Severe deficiency
IV. Adequate zone (maximum growth)
V. Hidden hunger (marginal deficiency)
Select the correct sequence:
(A) III, I, V, IV, II
(B) V, III, IV, I, II
(C) III, V, I, IV, II
(D) III, V, IV, I, II

2008

221. Phosphorus forms high-energy pyrophosphate bonds in which universal cellular energy carrier?
(A) ATP
(B) NADH
(C) FADH2
(D) Coenzyme A

2011

222. Nickel is required in incredibly small amounts, making it difficult to prove its essentiality. It is vital for preventing the toxic accumulation of which compound in plant tissues?
(A) Nitrate
(B) Urea
(C) Sulfite
(D) Ammonia

2008

223. "Reclamation disease" is a physiological disorder primarily affecting cereals grown on newly reclaimed peat soils due to a severe deficiency of:
(A) Manganese
(B) Zinc
(C) Iron
(D) Copper

2006

224. In highly alkaline soils (pH $>$ 8.0), phosphorus availability is sharply reduced because it precipitates with:
(A) Aluminum
(B) Iron
(C) Calcium
(D) Manganese

2008

225. Consider the following statements regarding passive ion absorption:
I. It requires direct ATP expenditure.
II. Ions enter the WFS by simple diffusion.
III. The DFS contains fixed negative charges.
IV. It is completely inhibited by metabolic poisons like cyanide.
V. It is a rapid and reversible process.
Which of the following represents the correct combination of statements?
(A) II, III, and V
(B) I, II, and III

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2016

184. When preparing a foliar nutritional spray, why is the optimal spray pH typically maintained slightly acidic (pH 5.0 to 6.0)?
(A) To keep nutrient salts (especially transition metals) in soluble, unprecipitated forms
(B) To prevent the cuticle from melting
(C) To cause temporary stomatal closure to avoid water loss
(D) To destroy competing epiphytic bacteria

2004

185. Consider the following statements regarding the rhizosphere:
I. Rhizosphere soil typically has a higher microbial population than bulk soil.
II. Root exudates can account for 10-20% of photosynthetically fixed carbon.
III. The rhizosphere extends exactly 1 meter away from the root surface.
IV. Phytosiderophores are specifically secreted under zinc and iron deficiency.
V. Roots cannot influence rhizosphere pH.
Which of the following represents the INCORRECT combination of statements?
(A) III and V
(B) I and II
(C) II and IV
(D) III and IV

2007

186. In the symbiotic association between leguminous plants and Rhizobium, the bacteria differentiate inside the nodule cells into specific nitrogen-fixing forms called:
(A) Endospores
(B) Bacteroids
(C) Heterocysts
(D) Mycelia

2011

187. Nitrogenase is a highly energy-demanding enzyme. How many high-energy electrons are needed to reduce one molecule of N_2 to two moles of NH_3, assuming optimal conditions without excess H_2 evolution?
(A) 2
(B) 4
(C) 8
(D) 16

2004

188. While most plants assimilate nitrate primarily in their leaves, temperate species and woody plants often reduce a significant portion of nitrate in their:
(A) Xylem vessels
(B) Flowers
(C) Roots
(D) Phloem sieve tubes

2009

189. In the synthesis of methionine, the sulfur atom is directly donated by:
(A) Cysteine
(B) Glutathione
(C) APS
(D) Sulfate

2008

190. To maximize Nitrogen Use Efficiency, modern agronomic recommendations emphasize applying nitrogen fertilizers:
(A) Exclusively at the time of sowing
(B) In multiple split doses synchronized with critical crop growth stages
(C) In a single massive dose midway through the season
(D) Entirely as foliar sprays during senescence

2016

191. The expression of the high-affinity phosphate transporter gene family (PHT1) is robustly induced under conditions of:
(A) High external phosphate
(B) Phosphate starvation
(C) Zinc toxicity
(D) Iron deficiency

NODIA

2005

192. Heavy metals like Lead (Pb) restrict plant growth primarily by inhibiting enzymes that contain specific active-site functional groups, particularly:
(A) Hydroxyl (-OH) groups
(B) Amino ($-NH_2$) groups
(C) Sulfhydryl (-SH) groups
(D) Carboxyl (-COOH) groups

2004

193. Which phytoremediation strategy utilizes plant roots to convert toxic, mobile metal species into highly insoluble, inert forms within the soil matrix, thereby preventing groundwater leaching?
(A) Phytostabilization
(B) Phytoextraction
(C) Phytovolatilization
(D) Phytoaccumulation

ANSWERS

1. (B) A plant cannot complete its vegetative or reproductive life cycle in the absence of the element.
Plant nutrients must meet specific criteria for essentiality according to Arnon and Stout. The most fundamental requirement is that the plant is unable to complete its entire life cycle, from vegetative growth to seed production, without the element. Additionally, the element's function must be direct and not replaceable by any other chemical element during plant development.

2. (C) Beneficial element
Beneficial elements are those that promote growth and development in certain plant species or under specific environmental conditions but are not strictly essential. Unlike essential nutrients, their absence does not prevent the plant from completing its life cycle or producing viable offspring. These elements often enhance plant resistance to biotic and abiotic stresses or improve overall metabolic efficiency.

3. (D) A.D. Nicholas
The term functional nutrients was introduced by Nicholas to broaden the classical definition of essentiality established by Arnon and Stout. This concept includes elements that promote plant growth or are essential for specific metabolic processes, even if they do not meet all three strict criteria. Examples include sodium for C4 plants and silicon for structural strength in grasses.

4. (A) Justus von Liebig
The Law of the Minimum states that plant growth is limited by the scarcest resource rather than the total amount of resources available. Formulated by Justus von Liebig, this principle emphasizes that increasing the supply of abundant nutrients will not improve yield if one specific nutrient remains deficient. It remains a foundational concept in soil fertility and modern agricultural fertilization practices.

5. (A) Both A and R are true and R is the correct explanation of A.
Sodium is not classified as an essential element for all higher plants because the majority of species can complete their reproductive cycles without it. While sodium is vital for certain C4 and CAM plants to maintain metabolic functions, it does not satisfy the universal criteria for essentiality. Therefore, the lack of a universal requirement supports its classification as a non-essential nutrient.

6. (B) Cu, B, Mo, Ni
Micronutrients are essential elements required by plants in very small quantities, typically less than one hundred milligrams per kilogram of dry matter. Copper, boron, molybdenum, and nickel are all recognized as essential micronutrients. They play critical roles in various biochemical processes, including enzyme activation, cell wall synthesis, nitrogen fixation, and urea metabolism, ensuring healthy development and reproduction.

7. (A) Poaceae
Silicon is particularly important for plants in the Poaceae family, which includes grasses and cereals like rice and wheat. It is deposited in the cell walls as opaline silica, providing structural rigidity and mechanical strength. This deposition enhances the plant's resistance to lodging and provides a physical barrier against pests, fungal pathogens, and various environmental stressors.

(C) Silicon directly participates in the electron transport chain during photosynthesis.
Silicon provides structural support and enhances stress tolerance in many plant species but does not directly participate in the photosynthetic electron transport chain. Other beneficial elements like cobalt are necessary for nitrogen fixation in legumes, while sodium can partially substitute for potassium in specific metabolic pathways. Selenium may replace sulfur in amino acids in certain accumulator plants.

9. (D) It is the structural metal component of urease for urea metabolism.
Nickel is recognized as an essential micronutrient because it serves as the central metal component of the enzyme urease. This enzyme is responsible for the hydrolysis of urea into ammonia and carbon dioxide, preventing the toxic accumulation of urea in plant tissues. Without

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sufficient nickel, plants cannot effectively manage nitrogen metabolism, leading to necrotic lesions and impaired growth.

10. (C) Sulfur
Sulfur is classified as a macronutrient due to the quantity required by plants, but its biochemical behavior often mirrors that of micronutrients. It frequently forms transient covalent bonds and is an integral part of various coenzymes and prosthetic groups. Sulfur is essential for synthesizing sulfur-containing amino acids like cysteine and methionine, which are crucial for protein structure and enzymatic activity.

11. (A) Yield is limited by nutrient deficiency without distinct visual symptoms.
Hidden hunger describes a specific condition in plant nutrition where the supply of a nutrient is insufficient to achieve maximum yield, yet the deficiency is not severe enough to cause visible symptoms. Farmers may be unaware of the limitation until the final harvest results are analyzed. Correcting this state through precise fertilization can significantly improve productivity without addressing obvious plant distress.

12. (D) Nutrient concentration decreases as initial growth responds to application.
The Steenbjerg effect occurs when the initial application of a limiting nutrient causes a rapid increase in biomass that outpaces the rate of nutrient uptake. This results in a paradoxical decrease in the internal concentration of that nutrient within the plant tissue despite its addition to the soil. This phenomenon is often observed in extremely deficient plants during early growth stages.

13. (A) Critical nutrient concentration
The critical nutrient concentration is the specific level in plant tissue below which growth or yield begins to decline significantly. It represents the boundary between the deficiency zone and the adequate supply zone. Maintaining nutrient levels at or slightly above this point ensures that the plant has sufficient resources for optimal physiological processes without entering the range of luxury consumption.

14. (C) Luxury consumption
Luxury consumption occurs when a plant continues to absorb nutrients from the soil beyond what is required for maximum growth and biomass production. During this phase, the internal concentration of the nutrient increases without providing any further yield benefit. While this does not harm the plant, it represents an inefficient use of fertilizers and can sometimes lead to nutrient imbalances.

15. (A) P-3, Q-4, R-2, S-1
Hidden hunger involves yield restriction without visible symptoms, while luxury consumption refers to nutrient uptake that does not lead to yield increases. The critical concentration is the tissue level where yield is approximately ten percent below the maximum possible. Finally, the Steenbjerg effect describes a reduction in tissue nutrient concentration due to a dilution effect upon initial nutrient application.

16. (D) Magnesium
Magnesium serves as the central atom in the porphyrin ring structure of the chlorophyll molecule, making it indispensable for photosynthesis. It coordinates with nitrogen atoms in the ring to stabilize the structure and facilitate light absorption. Beyond its role in chlorophyll, magnesium is a vital cofactor for many enzymes involved in energy metabolism and the synthesis of nucleic acids.

17. (B) Regulating stomatal opening and closing via osmotic potential.
Potassium acts as the primary osmoticum in plant cells, playing a crucial role in maintaining cell turgor and regulating the opening and closing of stomata. By moving in and out of guard cells, potassium ions control the water potential, allowing the plant to manage gas exchange and transpiration. It also activates numerous enzymes involved in protein synthesis and carbohydrate metabolism.

18. (B) It is an integral component of ATP, nucleic acids, and phospholipids.
Phosphorus is a vital structural and functional element in all living plant cells. It forms the backbone of nucleic acids, such as DNA and RNA, and is a key component of phospholipids in cell membranes. Most importantly, it is the central element in ATP, the primary molecule for energy transfer and storage during various metabolic and physiological processes.

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19. (D) Pectins to form calcium pectate
Calcium is essential for maintaining the structural integrity of plant cell walls and membranes. It primarily functions in the middle lamella, where it binds with pectic acid to form calcium pectate. This compound acts as a molecular glue that holds adjacent cells together. Sufficient calcium levels are necessary to prevent the collapse of tissues and ensure proper development of meristematic regions.

20. (A) Sulfate (SO_4^{2-})
Plants primarily absorb sulfur from the soil solution in the form of divalent sulfate anions. Once taken up by the roots, sulfate is transported through the xylem to the leaves, where it undergoes a series of reductive steps to be incorporated into organic compounds. These compounds include essential amino acids like cysteine and methionine, as well as various vitamins and cofactors.

21. (B) Zinc
Zinc is a critical micronutrient required for the biosynthesis of the plant hormone indoleacetic acid, which is the primary natural auxin. It facilitates the conversion of the amino acid tryptophan into IAA. Consequently, zinc deficiency often results in stunted growth, shortened internodes, and small, malformed leaves due to the lack of sufficient growth-regulating hormones within the developing plant tissues.

22. (A) Boron: Electron transport in the cytochrome b6f complex
Boron is involved in cell wall cross-linking and pollen tube growth but does not participate in the electron transport chain of the cytochrome b6f complex. In contrast, manganese is essential for the water-splitting reaction in Photosystem II, molybdenum is a core component of nitrate reductase, and iron is vital for the structure of cytochromes and ferredoxin in electron transport.

23. (C) Plastocyanin
Copper is an essential component of plastocyanin, a blue protein that functions as a mobile electron carrier in the photosynthetic electron transport chain. It facilitates the transfer of electrons from the cytochrome b6f complex to Photosystem I. Due to its redox properties, copper is also a vital cofactor for several other enzymes, including cytochrome c oxidase and superoxide dismutase.

24. (B) Osmoregulation and co-factor in the water-splitting complex of PSII.
Chlorine, absorbed as the chloride ion, is essential for plant growth due to its roles in osmoregulation and ionic balance. It serves as a critical cofactor in the oxygen-evolving complex of Photosystem II, where it facilitates the splitting of water molecules during photosynthesis. Additionally, chloride ions contribute to turgor pressure maintenance and are involved in the regulation of stomatal movements.

25. (A) I and II
Boron is an essential micronutrient that plays a fundamental role in the structural integrity of plant cell walls by cross-linking rhamnogalacturonan II molecules. It is also critical for reproductive development, specifically for the germination of pollen and the subsequent growth of the pollen tube. However, boron is not a component of the nitrogenase enzyme complex, which requires molybdenum and iron.

26. (B) Interveinal chlorosis on the youngest leaves
Iron is relatively immobile within the plant, meaning it cannot be easily retranslocated from older tissues to new growth. As a result, iron deficiency symptoms first appear on the youngest leaves. The characteristic symptom is interveinal chlorosis, where the leaf blades turn yellow or white while the veins remain green, reflecting the essential role of iron in chlorophyll biosynthesis.

27. (A) Molybdenum
Whiptail disease in cauliflower is a classic physiological disorder caused by a deficiency of molybdenum. The condition is characterized by the failure of the leaf lamina to develop properly, leaving only a thickened midrib that resembles a whip. Molybdenum is essential for the activity of nitrate reductase, and its deficiency leads to an accumulation of nitrate and impaired protein synthesis.

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28. (B) Calcium
Blossom-end rot in tomatoes and bitter pit in apples are common physiological disorders caused by a localized deficiency of calcium in the developing fruit. Because calcium is immobile in the phloem, it must be supplied continuously via the transpiration stream. Under conditions of low transpiration or high salt stress, insufficient calcium reaches the fruit tips, leading to cell wall collapse and necrosis.

mechanisms. One of the most significant ways they achieve this is by producing phytohormones, such as indoleacetic acid (IAA). These hormones stimulate the development and branching of the plant's root system, thereby increasing the total surface area available for the absorption of essential nutrients.

85. (A) Both A and R are true and R is the correct explanation of A.
Ectomycorrhizal fungi are characterized by the formation of a dense fungal mantle around the root tip and a network of hyphae called the Hartig net. Unlike arbuscular mycorrhizae, these fungi do not penetrate the plasma membrane of the host cells. Instead, the Hartig net grows exclusively between the epidermal and cortical cells, where it serves as the interface for nutrient exchange.

86. (A) Nitrogenase.
Nitrogenase is the unique enzyme complex that catalyzes the biological fixation of atmospheric nitrogen into ammonia. This vital process is performed exclusively by certain prokaryotes, including free-living bacteria and those in symbiotic associations with plants. The conversion of relatively inert N_2 gas into a biologically available form of nitrogen is essential for sustaining life and productivity in various ecosystems across the planet.

87. (A) Fe-protein (reductase) and MoFe-protein (dinitrogenase).
The nitrogenase enzyme complex is composed of two essential protein components: the Fe-protein and the MoFe-protein. The Fe-protein, or dinitrogenase reductase, is responsible for supplying high-energy electrons, while the MoFe-protein, or dinitrogenase, contains the catalytic site where nitrogen reduction actually occurs. Both proteins work together in a coordinated cycle, requiring significant amounts of ATP to drive the challenging reduction process.

88. (C) Oxygen.
Nitrogenase is extremely sensitive to oxygen and is rapidly and irreversibly inactivated in its presence. This sensitivity presents a significant challenge for nitrogen-fixing organisms, which must maintain a near-anaerobic environment for the enzyme while still meeting the high energy demands of the fixation process. Organisms have developed various strategies, such as specialized cells or oxygen-binding proteins, to protect the nitrogenase complex.

89. (C) Leghemoglobin.
In legume root nodules, leghemoglobin plays a crucial role in managing oxygen levels to protect the sensitive nitrogenase enzyme. This heme-containing protein binds oxygen with a very high affinity, maintaining a low free oxygen concentration within the nodule to prevent enzyme inactivation. Simultaneously, it facilitates a steady flux of oxygen to the respiring bacteroids, ensuring they have sufficient energy for nitrogen fixation.

90. (D) Flavonoids.
The complex process of legume nodulation is initiated by the plant root's secretion of specific signaling molecules, primarily flavonoids. These compounds are detected by soil-borne Rhizobium bacteria, which respond by producing Nod factors. These bacterial signals then trigger a series of developmental changes in the root, including root hair curling and the formation of the nodule primordium, leading to symbiotic association.

91. (A) Cytosol.
Nitrate reductase is the first enzyme involved in the assimilation of nitrate into organic compounds in plants. It catalyzes the reduction of nitrate to nitrite, utilizing electrons from NADH or NADPH. This enzyme is primarily located in the cytosol of the plant cells, both in the roots and the leaves. Its activity is highly regulated by various environmental factors, including light and nitrogen availability.

92. (D) Molybdenum.
Molybdenum is an essential trace element that serves as a central structural component of the molybdenum cofactor (Moco) in nitrate reductase. This pterin-based cofactor is critical for the enzyme's ability to transfer electrons to the nitrate substrate. Because of this requirement, molybdenum deficiency significantly impairs nitrate assimilation, leading to reduced nitrogen availability and stunted growth in many agricultural crops and wild plants.

93. (B) GS-GOGAT pathway.
The GS-GOGAT pathway is the primary route for the assimilation of ammonium into organic nitrogen in higher plants. It involves

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primarily by the concentration gradient through simple diffusion and by the movement of water through mass flow. Ions move from the higher concentration in the soil solution into the free spaces of the root cortex until equilibrium is reached.

39. (D) Volume where anions are repelled by fixed negative charges.
The Water Free Space is the portion of the apoplast where ions can move freely by diffusion without being influenced by fixed charges. It is the Donnan Free Space, not the WFS, where anions are repelled and cations are attracted by the negative charges of the cell wall. Ions in the WFS are in direct equilibrium with the external soil solution and can exchange rapidly.

40. (B) Crossing a semi-permeable plasma membrane.
Movement of ions into the symplastic pathway requires them to cross the semi-permeable plasma membrane, which serves as a selective barrier. This process is distinct from movement in the Apparent Free Space, which is entirely extracellular. Once inside the symplast, ions move from cell to cell through plasmodesmata, allowing the plant to regulate the type and amount of nutrients absorbed.

41. (C) Equilibrium potential for a specific ion across a membrane.
The Nernst equation is a fundamental tool in membrane bioenergetics used to calculate the electrical potential at which a specific ion would be in thermodynamic equilibrium across a membrane. By comparing the calculated Nernst potential with the actual measured membrane potential, researchers can determine whether an ion is being transported passively or actively against its electrochemical gradient in plant cells.

42. (D) K^+ is actively pumped into the cell against its gradient.
When the measured membrane potential of a plant cell is significantly more negative than the calculated Nernst equilibrium potential for potassium, it indicates that potassium is not moving passively. Instead, the plant must be using metabolic energy to actively transport K^+ ions into the cell against a concentration or electrical gradient. This active uptake is essential for maintaining high internal potassium concentrations.

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43. (A) Plasma membrane H^+-ATPase
The plasma membrane H^+-ATPase is the primary electrogenic pump in plants, utilizing energy from ATP hydrolysis to transport protons out of the cytoplasm into the apoplast. This action creates both a pH gradient and a strong negative electrical potential across the membrane. This electrochemical gradient provides the driving force for the secondary active transport of various other ions and solutes.

44. (C) Electrical potential gradient and pH gradient.
The proton motive force is the total potential energy stored across a membrane due to the action of proton pumps. it consists of two distinct components: the electrical potential gradient, resulting from the separation of charges, and the chemical pH gradient, resulting from the difference in proton concentration. Together, these gradients drive the passive and active movement of ions and molecules into the cell.

45. (A) Both A and R are true and R is the correct explanation of A.
Secondary active transport of anions into plant roots is powered by the proton motive force generated by H^+-ATPases. Anion-proton symporters facilitate this process by coupling the thermodynamically favorable inward movement of protons with the unfavorable inward movement of anions against their electrochemical gradient. This mechanism allows plants to efficiently accumulate essential nutrients like nitrate and phosphate from low-concentration soil solutions.

46. (A) Ion channels.
Ion channels are specialized transmembrane proteins that form selective pores, allowing for the very rapid passive movement of ions down their electrochemical gradient. These channels are often gated, meaning they open or close in response to specific stimuli such as voltage changes, mechanical stress, or signaling molecules. They play critical roles in rapid signaling, osmoregulation, and the adjustment of nutrient levels.

47. (C) Antiport.
Antiport is a mechanism of secondary active transport where a carrier protein moves two different solutes in opposite directions across a membrane. This process typically uses the energy from the downward movement of one ion, such as a proton, to drive the upward movement

of another solute against its gradient. A common example in plants is the sodium-proton antiporter used for salt tolerance.

48. (D) Undergo conformational changes to transfer bound ions.
Carrier proteins differ from ion channels in their mechanism of transport and speed. While channels form open pores for rapid diffusion, carriers must bind a specific solute and undergo a time-consuming conformational change to move it across the membrane. This results in a much slower transport rate. Carriers can be involved in both facilitated diffusion and primary or secondary active transport processes.

49. (C) Primary active transporter pumping protons into the vacuole.
The vacuolar H^+-pyrophosphatase is a primary active transporter located on the tonoplast. It utilizes the energy released from the hydrolysis of inorganic pyrophosphate to pump protons from the cytoplasm into the vacuole. Along with the V-ATPase, it helps maintain the acidic environment of the vacuole and generates the electrochemical gradient necessary for the sequestration of ions and metabolites.

50. (B) Compartmentalize toxic sodium ions into the vacuole.
Sodium-proton antiporters on the tonoplast are essential for plants to survive in saline environments. They use the proton gradient generated by vacuolar pumps to actively transport toxic sodium ions from the cytoplasm into the vacuole for storage. This compartmentalization prevents sodium from interfering with sensitive metabolic processes in the cytoplasm and helps maintain the cell's osmotic balance under salt stress.

51. (D) External ion concentration where uptake rate is half Vmax.
In nutrient uptake kinetics, the Michaelis constant represents the external concentration of an ion at which the rate of transport is exactly half of the maximum velocity. It serves as an important indicator of the affinity between the transport protein and the ion. A low value suggests a high affinity, meaning the transporter can function effectively even at very low soil concentrations.

52. (A) Extremely low (micromolar range)
The High-Affinity Transport System is a specialized mechanism that plants use to absorb nutrients when their concentrations in the soil solution are extremely low, typically in the micromolar range. This system is often inducible and relies on active transport processes to move ions against steep concentration gradients. It ensures that the plant can acquire essential nutrients even under conditions of soil depletion.

53. (C) Linear uptake kinetics without saturation at high levels.
The Low-Affinity Transport System generally operates when external nutrient concentrations are relatively high, usually in the millimolar range. Unlike the saturable High-Affinity Transport System, the LATS often exhibits linear uptake kinetics that do not saturate within typical physiological concentration ranges. This system is frequently mediated by ion channels or constitutive carriers and is important for rapid nutrient absorption during peak supply.

54. (A) Distinct transport systems operate at different ranges.
The dual-phasic or multiphasic curves observed in ion uptake studies reflect the presence of multiple, distinct transport systems within the root cell membranes. Each system, such as the HATS and LATS, has its own kinetic properties and operates optimally at different external concentration ranges. This allows the plant to efficiently acquire nutrients across the wide range of concentrations encountered in various soil environments.

55. (C) P-4, Q-2, R-1, S-3.
The maximum uptake velocity of a carrier system is represented by V_{max}, while the Michaelis constant indicates the carrier's affinity for an ion. The High-Affinity Transport System operates specifically at low external nutrient concentrations to ensure survival. In contrast, the Low-Affinity Transport System is characterized by non-saturating kinetics at moderate to high concentrations, facilitating bulk nutrient uptake when the soil supply is abundant.

56. (B) Symplastic pathway.
The symplastic pathway is the route through which water and solutes move through the interconnected living cytoplasm of adjacent plant cells. This movement is facilitated by

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plasmodesmata, which are microscopic channels that cross the cell walls. This pathway allows for the highly regulated and selective transport of nutrients and signaling molecules throughout the root tissue and eventually into the vascular system.

57. (C) Casparian strip.
The Casparian strip is a band of suberin and lignin deposited in the radial and transverse walls of endodermal cells. It acts as a waterproof barrier that effectively blocks the apoplastic movement of water and dissolved ions through the root cortex. To enter the vascular cylinder, solutes must cross the plasma membrane of the endodermis and enter the symplast, allowing control over uptake.

58. (D) Transcellular pathway.
The transcellular pathway is a radial transport route where water and solutes must cross the plasma membrane twice for each cell they pass through—once to enter and once to exit. This is distinct from the symplastic pathway, where solutes stay within the cytoplasm once they have entered. The transcellular route provides additional points for metabolic regulation and selective transport of nutrients.

59. (A) Apoplastic pathway.
Within the root cortex, the apoplastic pathway is the predominant route for the passive radial diffusion of ions from the soil solution toward the center of the root. This pathway consists of the interconnected network of cell walls and intercellular spaces. It allows for the relatively rapid movement of water and solutes until they reach the endodermis, where the Casparian strip forces them into the symplast.

60. (B) Endodermis.
The endodermis serves as a critical regulatory layer that prevents the uncontrolled back-leakage of ions from the vascular cylinder into the root cortex and soil. Once nutrients have been actively loaded into the xylem, the suberized Casparian strip in the endodermal cell walls acts as a physical barrier. This structural feature ensures that the high concentrations of nutrients required for translocation are maintained.

61. (B) Suberin and lignin.
The Casparian strip is a specialized modification of the endodermal cell wall composed primarily of suberin and lignin. Suberin is a complex, waxy, fatty substance that is highly impermeable to water and dissolved solutes, while lignin provides structural strength. Together, they create a hydrophobic seal that blocks the apoplastic route, ensuring all substances entering the plant's vascular system are filtered.

62. (A) Crossing a plasma membrane to enter the symplast.
Because the Casparian strip is impermeable to water and dissolved solutes, it effectively terminates the apoplastic pathway at the endodermis. This structural constraint forces all ions moving toward the center of the root to cross the semi-permeable plasma membrane and enter the living symplast. This transition allows the plant to selectively filter and regulate the types and quantities of nutrients absorbed.

63. (C) Passage cells.
In older parts of the root where the endodermis may become heavily suberized or thickened, certain cells known as passage cells remain thin-walled and lack extensive suberin deposits. These cells provide low-resistance points that allow for the continued symplastic movement of water and minerals into the stele. They are essential for maintaining the transport of nutrients from the cortex to vascular tissues.

64. (D) Xylem parenchyma cells.
Xylem loading is the process by which ions are transferred from the symplast of the root into the dead conducting elements of the xylem. This process is primarily mediated by specialized transport proteins located on the plasma membranes of the living xylem parenchyma cells. These cells actively or passively release ions into the xylem vessels, creating the necessary concentration for long-distance transport.

65. (A) I and III.
Xylem loading is a highly regulated process involving both active and passive transport mechanisms. Specific outward-rectifying potassium channels, such as SKOR, are responsible for releasing potassium into the xylem vessels. Furthermore, the living xylem parenchyma cells play an active role in transporting various ions across their membranes into the tracheary elements, contradicting the idea that the process is strictly passive.

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66. (B) Transpiration stream.
The bulk movement of water and dissolved minerals from the roots to the shoots through the xylem is predominantly driven by the transpiration stream. As water evaporates from the leaves, it creates a negative pressure or tension that pulls the column of water upward through the xylem vessels. This process, known as the cohesion-tension mechanism, allows for the efficient long-distance transport of nutrients.

67. (D) Bidirectional, moving from sources to sinks.
Transport in the phloem is fundamentally different from xylem transport because it is bidirectional and occurs within living sieve tube elements. Phloem sap moves from source tissues, where sugars and nutrients are produced or stored, to sink tissues, such as growing roots, fruits, or young leaves, where they are consumed. This movement is driven by pressure gradients created by active loading.

68. (A) Calcium.
Calcium is characterized by its very low mobility within the plant's phloem system. Once it has been translocated to a specific tissue via the xylem and incorporated into cell walls, it cannot be easily remobilized to other parts of the plant. Consequently, when a deficiency occurs, symptoms such as necrosis and distorted growth appear first in the youngest leaves and developing meristems.

69. (C) Boron is universally highly mobile in the phloem of all plant species.
The mobility of boron in the phloem varies significantly between plant species. While it is highly mobile in species that produce polyols like sorbitol, it is relatively immobile in many others. On the other hand, nitrogen is versatile and moves through the xylem as nitrate or amino acids. Xylem unloading is essential for leaf cell utilization, and magnesium is generally considered mobile.

70. (A) Extensive plasma membrane invaginations to increase surface area.
Transfer cells are specialized parenchyma cells that facilitate the intensive short-distance transport of solutes between different vascular tissues. Their most defining feature is the presence of extensive, inward-growing cell wall projections and corresponding plasma membrane invaginations. This structure dramatically increases the surface area available for transport proteins, allowing for high rates of nutrient exchange between xylem and surrounding cells.

71. (D) Cuticle.
The primary structural barrier that limits the absorption of nutrients applied as foliar sprays is the leaf cuticle. This hydrophobic layer, composed of cutin and waxes, is designed to minimize water loss and protect the leaf from environmental damage. Its non-polar nature makes it difficult for aqueous nutrient solutions to penetrate, requiring the use of specialized formulations or surfactants.

72. (C) Submicroscopic polar pathways in the leaf cuticle.
Ectodesmata are submicroscopic, polar pathways or channels that extend through the leaf cuticle toward the outer epidermal cell wall. Although they are not open pores like stomata, they provide preferential routes for the penetration of polar water-soluble nutrients and pesticides into the leaf tissue. Understanding these pathways is crucial for optimizing the delivery of foliar fertilizers and improving overall crop treatment effectiveness.

73. (A) High relative humidity.
High relative humidity significantly enhances the absorption efficiency of foliar-applied nutrients. It slows the evaporation of the spray droplets, keeping the nutrients in a dissolved state on the leaf surface for a longer period. Additionally, high humidity can cause the cuticle to swell and become more permeable, facilitating the movement of ions through the waxy barrier into the underlying epidermal cells.

74. (C) Correcting iron chlorosis in alkaline, calcareous soils.
Foliar nutrition is highly effective for correcting micronutrient deficiencies, such as iron chlorosis, especially in alkaline or calcareous soils where these elements are quickly rendered unavailable to the roots. By applying nutrients directly to the leaves, the plant can bypass the soil-related problems of precipitation and fixation. This method provides a rapid response and is often used as a supplement.

75. (C) II only.
Nutrients absorbed through the leaves can indeed be translocated to the roots, especially

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if they are phloem-mobile elements like nitrogen or potassium. Surfactants are commonly added to foliar sprays to improve leaf coverage by reducing the contact angle of the droplets. Urea is a popular nitrogen source for foliar application due to its high permeability, though application rates must prevent leaf burn.

76. (B) Rhizosphere.
The rhizosphere is the narrow zone of soil that is directly influenced by the presence and activities of plant roots. It is characterized by high microbial activity and altered chemical properties compared to the surrounding bulk soil. This region is where critical interactions occur between the plant, soil microorganisms, and nutrients, driven by the release of various root exudates that shape environment.

77. (A) Solubilize phosphorus and complex toxic aluminum.
Plant roots frequently secrete organic acids, such as citrate and malate, into the rhizosphere as a strategy to improve nutrient availability. These acids can solubilize inorganic phosphorus by displacing it from soil particles or by chelating the metal ions to which it is bound. Furthermore, organic acids can complex and detoxify soluble aluminum in acidic soils, protecting the sensitive root tips.

78. (C) Iron.
Siderophores are low-molecular-weight organic compounds with an extremely high affinity for ferric iron. They are produced and secreted by soil microbes and some plant species (known as phytosiderophores) to combat iron deficiency. By chelating insoluble iron in the soil, siderophores create soluble complexes that can be readily absorbed by the organism, ensuring an adequate supply of this essential micronutrient.

79. (D) Proton extrusion and reduction of Fe^{3+} to Fe^{2+}.
Strategy I plants, which include dicots and non-graminaceous monocots, acquire iron through a two-step process in the rhizosphere. First, they acidify the soil by extruding protons via plasma membrane H^+-ATPases, which increases iron solubility. Subsequently, a specialized membrane-bound reductase enzyme reduces ferric iron (Fe^{3+}) to the more soluble ferrous form (Fe^{2+}), which is then transported into root cells.

80. (B) Secreting phytosiderophores that complex Fe^{3+}.
Strategy II plants, primarily grasses such as wheat and rice, have evolved a distinct mechanism for iron acquisition. Under iron-deficient conditions, they secrete phytosiderophores into the rhizosphere. These compounds bind strongly to ferric iron (Fe^{3+}), forming a soluble complex. The entire iron-phytosiderophore complex is then recognized and taken up by specific transporters on the root plasma membrane, enabling growth in iron-poor soils.

81. (B) Phosphorus.
Arbuscular Mycorrhizal Fungi form a symbiotic relationship with the majority of land plants, primarily enhancing the acquisition of immobile soil nutrients like phosphorus. The fungal hyphae extend far beyond the root's depletion zone, increasing the effective surface area for nutrient absorption. This association is particularly beneficial in phosphorus-limited soils, as the fungi can access and transport phosphate more efficiently than roots.

82. (A) Arbuscules.
Arbuscules are the characteristic, highly branched hyphal structures that form within the cortical cells of the host plant's root during AMF colonization. They are the primary sites for the exchange of nutrients between the fungus and the plant. The fungus delivers phosphorus and other minerals to the plant, while the plant provides photosynthetically derived carbohydrates to the fungus, supporting their mutualistic relationship.

83. (D) Producing organic acids and acid phosphatases.
Phosphorus-solubilizing bacteria improve the availability of phosphorus in the rhizosphere through several mechanisms. They secrete organic acids that lower the soil pH and chelate metal ions, thereby releasing bound inorganic phosphate. Additionally, these bacteria produce acid phosphatases, which are enzymes that catalyze the mineralization of organic phosphorus compounds into soluble forms that can be readily absorbed by the root system.

84. (A) Producing phytohormones like IAA to stimulate root system development.
Plant Growth-Promoting Rhizobacteria enhance the nutritional status and overall growth of plants through various direct and indirect

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29. (B) Application of zinc sulfate to soil or as a foliar spray.
Khaira disease in rice is a significant nutritional disorder caused by zinc deficiency, particularly common in calcareous or submerged soils. The most effective agronomic practice to correct this condition is the application of zinc sulfate, either directly to the soil before transplanting or as a foliar spray. This provides an immediate source of available zinc to the rice plants.

30. (A) Potassium - Potato
Indicator plants are specific species that show clear and characteristic deficiency symptoms when a particular nutrient is lacking in the soil. The potato plant is widely recognized as an indicator for potassium deficiency, showing distinct marginal bronzing and necrosis on its leaves. Utilizing these plants helps farmers and agronomists diagnose soil nutrient shortages and implement timely corrective fertilization strategies.

31. (C) Sulfate is reduced to toxic hydrogen sulfide.
In waterlogged soils, the depletion of oxygen leads to a significant drop in redox potential. Under these highly reducing conditions, anaerobic microorganisms use sulfate as an alternative electron acceptor, reducing it to hydrogen sulfide. This gas can be toxic to plant roots and contributes to the chemically hostile environment found in poorly drained, anaerobic soil systems.

32. (D) Decreases as they precipitate as insoluble hydroxides.
The availability of most micronutrients, such as iron, manganese, zinc, and copper, is strongly influenced by soil pH. As the pH rises and the soil becomes more alkaline, these metal ions tend to react with hydroxyl ions to form insoluble hydroxides or oxides. This precipitation reduces the concentration of available nutrients in the soil solution, often leading to widespread deficiency symptoms.

33. (C) Molybdenum
Unlike most other micronutrients whose availability decreases in alkaline conditions, molybdenum becomes more soluble as the soil pH rises above seven. In acidic soils, molybdenum is strongly adsorbed to iron and aluminum oxides, making it unavailable to plants. Liming acidic soils is a common practice to increase the pH and enhance the availability of molybdenum for crops, especially for legumes.

34. (B) Inhibiting root elongation and restricting nutrient uptake.
In highly acidic soils, aluminum becomes soluble in the form of toxic Al^{3+} ions. These ions quickly penetrate the root tips, where they interfere with cell division and cell wall expansion. This inhibition leads to stunted, stubby root systems that are unable to explore the soil effectively. Consequently, the plant suffers from restricted water and nutrient uptake, severely limiting overall growth.

35. (C) II only
Low soil temperatures actually decrease phosphorus uptake because they reduce root metabolic activity and membrane fluidity, making diffusion and active transport more difficult. Conversely, high organic matter increases micronutrient availability through chelation, and soil compaction hinders the diffusion of potassium. Additionally, low redox potential in flooded soils increases the solubility of iron and manganese, potentially leading to toxic levels.

36. (D) Water Free Space (WFS) and Donnan Free Space (DFS)
The Apparent Free Space refers to the total volume in the root tissue that is accessible to external solutes via passive diffusion. it is composed of two distinct components: the Water Free Space and the Donnan Free Space. While the WFS allows for the free movement of all ions, the DFS contains fixed negative charges that influence the distribution of cations and anions.

37. (C) Carboxyl groups of cell wall pectins.
The Donnan Free Space is characterized by the presence of non-diffusible, fixed negative charges within the root cell walls. These charges primarily arise from the ionized carboxyl groups of pectic acids found in the middle lamella and primary cell wall. These negative sites attract and hold cations from the soil solution while repelling anions, creating an electrochemical equilibrium in the apoplast.

38. (A) Diffusion and mass flow.
Passive ion absorption into the Apparent Free Space is a physical process that does not require the expenditure of metabolic energy. It is driven

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two enzymes: glutamine synthetase, which incorporates ammonium into glutamate to form glutamine, and glutamate synthase, which transfers the amide group to alpha-ketoglutarate, producing two molecules of glutamate. This cycle ensures the efficient and safe incorporation of ammonium, preventing its toxic accumulation.

94. (A) It is located in the cytosol of leaf cells.
Nitrite reductase is located in the chloroplasts of leaf cells and the plastids of root cells, not in the cytosol. This enzyme is responsible for the six-electron reduction of nitrite to ammonium. In the leaves, it utilizes reduced ferredoxin from the photosynthetic light reactions as an electron donor. This specific localization and high activity are essential to prevent toxic nitrite buildup within the cell.

95. (A) P-2, Q-1, R-4, S-3.
Nitrate reductase is found in the cytosol, where the first step of nitrate reduction occurs. Nitrite reductase and the GS2 isoform of glutamine synthetase are both located within the chloroplasts or plastids to facilitate the subsequent steps of nitrogen assimilation. Finally, the nitrogenase enzyme complex is housed within the bacteroids of legume nodules, where it carries out the vital process of biological nitrogen fixation.

96. (D) Adenosine 5'-phosphosulfate (APS)
Before sulfate can be utilized by the plant for the synthesis of organic compounds, it must be chemically activated because the sulfate ion is relatively stable. This activation process involves the reaction of sulfate with ATP to form adenosine 5'-phosphosulfate. APS serves as a high-energy intermediate that can then be reduced to sulfite or used in other sulfur-related metabolic pathways.

97. (C) ATP sulfurylase.
The activation of sulfate to adenosine 5'-phosphosulfate is catalyzed by the enzyme ATP sulfurylase. This reaction is the first committed step in the sulfur assimilation pathway. The enzyme facilitates the replacement of two phosphate groups from ATP with a sulfate group. Once formed, APS can be further processed by APS reductase to continue the pathway toward the synthesis of cysteine and other vital molecules.

98. (B) Cysteine.
Cysteine is the first stable organic compound formed during the primary assimilation of sulfur in plants. It is synthesized by the enzyme O-acetylserine (thiol) lyase, which incorporates sulfide into the carbon backbone of O-acetylserine. Cysteine serves as the central sulfur donor for the synthesis of all other organic sulfur-containing compounds, including the amino acid methionine, various proteins, vitamins, and the antioxidant glutathione.

99. (C) Glutathione.
Cysteine is an essential precursor for the biosynthesis of glutathione, which is a major cellular antioxidant in plants. Glutathione is a tripeptide composed of glutamate, cysteine, and glycine, and it plays a critical role in protecting cells against oxidative stress caused by reactive oxygen species. It is also involved in the detoxification of heavy metals and the regulation of sulfur metabolism throughout developmental stages.

100. (A) Crucifers (Brassicaceae)
Plants in the Brassicaceae family, such as mustard, canola, and cabbage, have a significantly higher requirement for sulfur than most other crop families. This is largely due to their unique metabolic pathways that produce sulfur-rich secondary metabolites known as glucosinolates. These compounds are responsible for the characteristic pungent flavor and odor of crucifers and play an important role in the plant's defense mechanisms.

101. (B) (Yield change) / (Amount of fertilizer applied).
Agronomic Nutrient Use Efficiency is a practical measure used to assess the economic benefit of fertilizer application. It is mathematically defined as the increase in crop yield per unit of nutrient applied from the fertilizer. This indicator helps farmers determine the most cost-effective fertilization rates and evaluate the overall performance of different management practices in maximizing productivity while minimizing unnecessary agricultural inputs.

102. (C) The ability of the plant to convert absorbed nutrients into economic yield
Physiological Nutrient Use Efficiency refers to the efficiency with which a plant converts the nutrients it has already absorbed into economic

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Arbuscular Mycorrhizal Fungi often provides several other benefits to the host plant. These include enhanced tolerance to drought stress, as the fungal hyphae can access water in smaller soil pores. Furthermore, AMF can help protect the plant against various soil-borne pathogens by competing for resources, inducing defense mechanisms, or physically blocking the infection sites on the roots, improving resilience.

155. (C) 16.
Biological nitrogen fixation is an extremely energy-intensive process. According to the balanced chemical equation, the reduction of one molecule of nitrogen gas to two molecules of ammonia requires at least sixteen molecules of ATP. This energy is needed to provide the high-energy electrons required for the reduction and to overcome the strong triple bond of the N_2 molecule. The high demand for ATP explains why nitrogen fixation is often limited by photosynthesis.

156. (C) Uptake hydrogenase (Hup).
During the process of nitrogen fixation, some of the energy and electrons are inevitably diverted to the production of hydrogen gas as a byproduct. To improve efficiency, certain strains of rhizobia possess an enzyme called uptake hydrogenase. This enzyme recycles the produced hydrogen by oxidizing it back to protons and electrons, which can then be used to generate additional ATP or protect the nitrogenase. Rhizobial strains with Hup activity are more efficient.

157. (C) Much higher than that of nitrate reductase.
Nitrite is a highly reactive and toxic compound that can damage plant cells if it is allowed to accumulate. To prevent this, the activity of nitrite reductase, which converts nitrite to ammonium, is typically much higher than the activity of nitrate reductase, which produces the nitrite. This ensures that any nitrite formed is rapidly processed through the assimilation pathway. This careful balance of enzymatic activity is a critical regulatory mechanism.

158. (B) Glutamate to form glutamine.
Glutamine synthetase is a key enzyme in nitrogen metabolism that catalyzes the ATP-dependent incorporation of ammonium into the amino acid glutamate, resulting in the formation of glutamine. This reaction is the first step in the assimilation of inorganic ammonium into organic nitrogen compounds. By converting potentially toxic ammonium into a stable amide, glutamine synthetase plays a vital role in nitrogen transport, storage, and the subsequent synthesis of amino acids.

159. (C) Two molecules of glutamate.
The enzyme GOGAT, also known as glutamate synthase, plays a crucial role in the GS-GOGAT cycle of nitrogen assimilation. It facilitates the transfer of the amide amino group from a molecule of glutamine to a molecule of alpha-ketoglutarate. This reaction results in the production of two molecules of glutamate. One of these glutamate molecules can be recycled by glutamine synthetase to continue the assimilation process, while the other is used for amino acid synthesis.

160. (D) Chloroplasts/Plastids.
The primary steps of sulfur reduction and assimilation in plants, including the conversion of APS to sulfite and subsequently to sulfide, predominantly occur within the chloroplasts of leaf cells and the plastids of root cells. These organelles provide the necessary reducing power, often in the form of reduced ferredoxin from photosynthesis light reactions. The localization ensures resulting sulfide is immediately available for the synthesis of cysteine and other compounds.

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161. (C) Sulfur is relatively immobile within the plant.
Sulfur is generally considered to be relatively immobile within the plant's vascular system. Unlike nitrogen or potassium, which can be easily retranslocated from older tissues to support new growth, sulfur tends to remain in the leaves where it was first incorporated into proteins and other molecules. Therefore, when the soil supply is inadequate, the younger leaves are the first to show symptoms of deficiency, typically appearing as a uniform chlorosis.

162. (D) Absorbs nutrient well but fails to convert it to yield.
A crop that exhibits a high nutrient uptake efficiency but a low physiological nutrient use efficiency is one that is very effective at absorbing the available nutrients from the soil but is relatively poor at using those internal resources to produce economic yield. This situation might occur due to genetic limitations, environmental stresses that interfere with metabolic processes,

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111. (B) Phytochelatin synthase
Phytochelatin synthase is the constitutive enzyme responsible for the synthesis of phytochelatins from glutathione precursors. The enzyme is specifically activated by the presence of heavy metal ions such as cadmium, lead, and mercury. Once activated, it catalyzes the formation of these sulfur-rich peptides, which play a central role in the chelation and detoxification of toxic metals within the plant cell, preventing widespread cellular damage.

112. (B) Gene-encoded, cysteine-rich, low-molecular-weight proteins
Unlike phytochelatins, which are enzymatically synthesized peptides, metallothioneins are small, cysteine-rich proteins that are directly encoded by genes. They are involved in the homeostasis of essential metals like copper and zinc and the detoxification of toxic heavy metals. Their high cysteine content allows them to bind metal ions through thiol groups. Metallothioneins are found across a wide range of organisms and are categorized into classes.

113. (C) Phytoextraction
Phytoextraction is a phytoremediation technique that utilizes specific plant species to absorb toxic heavy metals from contaminated soil or water. The absorbed metals are then translocated and concentrated within the harvestable shoot tissues, such as leaves and stems. Once the plants have reached maturity, they are harvested and disposed of safely, effectively removing the contaminants from the site and reducing environmental risk from pollution.

114. (B) Selenium and Mercury
Phytovolatilization is a specialized form of phytoremediation where plants absorb certain elements from the soil and release them into the atmosphere as less toxic gases. This process is particularly useful for the remediation of selenium and mercury. Plants can metabolically transform these elements into volatile forms, such as dimethylselenide or elemental mercury vapor, which are then transpired through the leaves, reducing local soil concentrations.

115. (C) II only
Hyperaccumulator plants are defined by their ability to actively translocate and concentrate extremely high levels of heavy metals within their shoot tissues, not just their roots. They achieve this without showing toxicity symptoms, often by sequestering the metals in leaf vacuoles. Species like Thlaspi caerulescens are well-documented for their exceptional ability to accumulate zinc and cadmium, making them valuable for studying metal tolerance and phytoremediation.

116. (C) Cobalt
Cobalt is recognized as a beneficial element that is essential for the growth of symbiotic nitrogen-fixing bacteria, such as Rhizobium. It is a central component of cobalamin, or Vitamin B12, which is required by several bacterial enzymes involved in nitrogen fixation and nodule metabolism. While not essential for the plant itself, cobalt is necessary for the successful establishment and function of the legume-Rhizobium symbiosis.

117. (A) A non-essential element taken up via luxury consumption or passive influx.
If a plant contains high concentrations of an element but grows and reproduces normally without it, that element is considered non-essential. Such elements may be absorbed passively through the roots or via luxury consumption when they are abundant in the environment. Their presence does not indicate a physiological requirement, and they do not participate in any vital metabolic pathways necessary for the plant's life cycle.

118. (D) 90-95%
Carbon, hydrogen, and oxygen are the primary structural elements of plants, together constituting approximately ninety to ninety-five percent of the total dry matter. These elements are obtained from carbon dioxide in the air and water from the soil through the processes of photosynthesis and respiration. They form the backbone of all organic molecules, including cellulose, starch, proteins, and lipids, which build the physical structure.

119. (C) Concentration in tissue exceeds 10 mmol/kg dry weight.
The primary distinction between macronutrients and micronutrients is the quantity required by the plant for healthy growth. Macronutrients are defined as those essential elements whose concentration in plant tissue is equal to or greater than ten millimoles per kilogram of dry weight. In contrast, micronutrients are needed in much smaller amounts. Both groups are equally

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yield, such as grain or biomass. It reflects the internal metabolic processes and the plant's ability to allocate resources effectively to the harvestable parts. Improving this efficiency is a key goal for plant breeders aiming to develop varieties that produce more food.

103. (B) Yield increase is proportional to decrement from max.
The Mitscherlich yield equation is based on the principle that the increase in yield produced by a unit of a limiting nutrient is proportional to the difference between the maximum possible yield and the current yield. As the yield approaches its maximum potential, the response to additional fertilizer decreases. This concept of diminishing returns is fundamental for understanding crop response curves and optimizing fertilizer applications.

104. (A) Nitrogen in the grain / Total above-ground plant nitrogen
The Nitrogen Harvest Index is a measure of the efficiency with which a plant remobilizes nitrogen from its vegetative tissues into the harvested grain. It is calculated as the ratio of nitrogen contained in the grain to the total above-ground plant nitrogen at maturity. A high NHI indicates that a large proportion of the plant's nitrogen resources have been successfully allocated to the economically valuable portion.

105. (A) II and III
Internal utilization efficiency is defined as the grain yield achieved divided by the total nutrient uptake, reflecting how well the plant uses its internal resources. Additionally, modern precision farming tools like SPAD meters are effective for monitoring leaf nitrogen status and improving overall nitrogen use efficiency. However, a high apparent recovery efficiency does not always guarantee high agronomic efficiency without proper conversion.

106. (A) PHR1 (Phosphate Starvation Response 1)
PHR1 is a master transcription factor that plays a central role in the plant's response to phosphate deficiency. Under low phosphorus conditions, PHR1 is upregulated and activates the expression of numerous genes involved in phosphate acquisition and recycling. These include high-affinity phosphate transporters and enzymes that help the plant scavenge phosphorus from its environment, thereby improving overall phosphorus use efficiency and survival.

107. (C) High-affinity root transporter genes like NRT2
A common transgenic approach to improve Nutrient Use Efficiency involves the overexpression of genes encoding high-affinity root transporters, such as those in the NRT2 family for nitrate. By increasing the number or efficiency of these transporters, researchers aim to enhance the plant's ability to capture nutrients from low-concentration soil environments. This can lead to improved growth and yield under nutrient-limited conditions.

108. (C) Remobilizing macromolecules from old leaves to sinks.
Autophagy is a critical cellular degradation process that enhances plant Nutrient Use Efficiency by recycling macromolecules and organelles. During senescence or nutrient stress, autophagy helps break down proteins and other structures in older leaves, releasing nutrients that can then be remobilized to actively growing tissues or developing seeds. This internal recycling mechanism is essential for maximizing the use of limited nutrients within the plant.

109. (D) Inducing oxidative stress and displacing essential metals from metalloproteins
Cadmium causes cellular toxicity in plants through several damaging mechanisms. It induces the overproduction of reactive oxygen species, leading to oxidative stress and damage to lipids, proteins, and DNA. Furthermore, cadmium can displace essential metal ions, such as zinc or iron, from the active sites of metalloproteins and enzymes, thereby disrupting vital metabolic processes and severely inhibiting overall growth and development.

110. (B) Glutathione
Phytochelatins are metal-binding peptides synthesized by plants in response to heavy metal exposure. They are polymerized directly from glutathione molecules through the action of the enzyme phytochelatin synthase. These peptides function by chelating toxic heavy metal ions in the cytoplasm and facilitating their subsequent sequestration into the vacuole. This process is a fundamental mechanism for heavy metal detoxification and tolerance in many plants.

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fixation and is also involved in other processes such as pH regulation.

129. (D) Zinc
"Little leaf" and "rosette" are classic visual symptoms of zinc deficiency in various fruit trees and crops. These conditions occur because zinc is required for the synthesis of auxins, which regulate cell elongation. A lack of zinc leads to shortened internodes, resulting in a crowded, rosette-like appearance of the foliage, and the development of abnormally small leaves. Correcting zinc deficiency is essential for canopy structure.

130. (B) Foliar spray of iron chelates (e.g., Fe-EDTA or Fe-EDDHA).
To rapidly correct acute iron chlorosis in high-value crops growing on alkaline, calcareous soils, the most effective method is the foliar application of iron chelates. On such soils, soil-applied iron salts quickly become insoluble and unavailable to the roots. Foliar sprays bypass the soil constraints, delivering available iron directly to the leaves where it is needed for chlorophyll synthesis, providing a fast and visible recovery.

131. (A) Crinkle leaf
Manganese toxicity often manifests in plants as "crinkle leaf," a condition characterized by brown necrotic spots on older leaves and a distorted, puckered appearance of the leaf lamina. This toxicity typically occurs in highly acidic soils where manganese solubility increases to dangerous levels. The excess manganese can interfere with the uptake and function of other essential nutrients, leading to metabolic imbalances and significant reductions in growth.

132. (D) Fe, Mn, Zn, and Cu.
Calcareous soils are characterized by a high pH and the presence of significant amounts of calcium carbonate. These conditions typically induce deficiencies in several essential micronutrients, including iron, manganese, zinc, and copper. At high pH levels, these metal ions react to form insoluble hydroxides and carbonates, drastically reducing their availability in the soil solution. Managing these soils often requires the use of specialized fertilizers.

133. (C) Below 6.5 it precipitates with Fe and Al; above 6.5 it precipitates with Ca.
The availability of phosphorus in the soil is highly sensitive to pH, peaking around 6.5. In acidic soils (pH below 6.5), phosphate ions tend to react with iron and aluminum to form insoluble minerals. In alkaline soils (pH above 6.5), they react with calcium to form insoluble calcium phosphates. At a slightly acidic to neutral pH of 6.5, these precipitation reactions are minimized, leaving more soluble form available.

134. (B) Zinc
The excessive application of phosphorus fertilizers can inadvertently induce a zinc deficiency in plants. This antagonism occurs because high phosphate levels can interfere with the uptake of zinc by the roots or its translocation within the plant. In some cases, insoluble zinc phosphates may also form within the soil or root tissue. Maintaining a proper balance between these two nutrients is crucial for preventing physiological disorders.

135. (A) P-1, Q-3, R-2, S-4.
The Water Free Space consists of the readily exchangeable ions found in the intercellular spaces of the root. The Donnan Free Space is characterized by the presence of fixed, non-diffusible negative charges within the cell walls. The symplast represents the continuous network of living cytoplasm interconnected by plasmodesmata. Finally, the apoplast refers to the entire extracellular continuum of cell walls and intercellular spaces surrounding the living cells.

136. (C) Higher than the external solution.
In the Donnan Free Space of plant roots, the presence of fixed negative charges on the cell wall components, such as pictins, creates an electrochemical attraction for mobile cations. To maintain electrical neutrality, the concentration of cations within this space becomes significantly higher than in the surrounding external soil solution. This phenomenon helps the plant concentrate essential positively charged nutrients near the plasma membrane, facilitating their subsequent absorption.

137. (B) Electrochemical potential difference for ion j.
The provided equation is used to calculate the electrochemical potential difference for a specific ion across a biological membrane. It

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combines the chemical potential, derived from the concentration gradient, and the electrical potential, resulting from the charge of the ion and the membrane voltage. Understanding this difference is fundamental for determining the thermodynamic driving force and the direction of spontaneous ion movement in plant cells.

138. (B) The ion is at thermodynamic equilibrium across the membrane.
When the electrochemical potential difference for a specific ion across a membrane is zero, it signifies that the ion is at thermodynamic equilibrium. At this state, there is no net driving force for the movement of the ion into or out of the cell, and the inward and outward fluxes are equal. If the measured concentration of an ion deviates from this state, it indicates active transport mechanisms are employed.

139. (C) Urea and boric acid.
Aquaporins are primarily known as specialized channel proteins that facilitate the rapid and selective movement of water across plant membranes. However, some specific isoforms of these proteins can also transport certain small, uncharged solute molecules. These include urea, which is important for nitrogen metabolism, and boric acid, which is the form in which boron is primarily absorbed and translocated. This versatility allows plants to manage water and nutrients.

140. (C) They exclusively transport protons to generate the membrane potential.
ABC transporters are a large family of primary active transporters that utilize the energy from ATP hydrolysis to move a variety of substrates across membranes, but they are not primary generators of membrane potential. That role belongs to H^+-ATPases. ABC transporters are involved in many processes, including transport of hormones and the sequestration of heavy metal-phytochelatin complexes into the vacuole, contributing to plant detoxification.

141. (A) The High-Affinity Transport System (HATS).
When the external concentration of nitrate is very low, such as 0.05 mM, the plant primarily relies on the High-Affinity Transport System for its uptake. The HATS is specifically designed to function efficiently in the micromolar range, allowing roots to scavenge nitrate from depleted soil solutions. This system involves active transport mechanisms and is often strongly regulated by the plant's overall nitrogen status, ensuring survival and growth.

142. (B) Strongly upregulated under nitrogen starvation.
The expression of genes encoding high-affinity nitrate transporters, such as those in the NRT2 family, is highly sensitive to the plant's internal nitrogen levels. When a plant experiences nitrogen starvation, these genes are robustly upregulated to increase the root's capacity for nitrate absorption from the soil. This physiological response allows the plant to maximize its chances of acquiring nitrogen once it becomes available, thereby compensating for deficient environmental conditions.

143. (A) Plasmodesmata.
The resistance to the flow of water and dissolved solutes within the root's symplastic pathway is primarily determined by the frequency and conductance of the plasmodesmata. These microscopic channels connect the cytoplasm of adjacent cells, providing the only route for symplastic movement. The plant can regulate this resistance by changing the number of plasmodesmata or by altering their effective diameter, thereby controlling the rate of transport across the root.

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144. (C) Plasma membranes of the same cell twice (entering and exiting).
The transcellular pathway is a radial transport route that is distinct from the purely symplastic or apoplastic pathways. In this route, water and solutes must cross the plasma membrane of each cell they encounter twice—once to enter the cytoplasm from the cell wall and once to exit back into the cell wall of the next cell. This repeated crossing provides the plant with multiple opportunities to selectively regulate the flow of substances.

145. (A) I, II, III, and V.
The Casparian strip in the endodermis is a vital structure that blocks the apoplastic pathway and prevents the back-leakage of actively loaded ions. In some roots, an exodermis with its own Casparian band can form a second barrier. While passage cells remain thin-walled to allow for symplastic transport in older roots, suberin is generally impermeable to both water

and solutes, making the idea that it allows free diffusion incorrect.

146. (A) Active accumulation of ions in the xylem sap of the stele.
Root pressure is an osmotic phenomenon that occurs when ions are actively accumulated in the xylem sap of the root stele. This increase in solute concentration lowers the water potential, causing water to move from the soil into the xylem by osmosis. The resulting positive pressure can push the xylem sap upward, sometimes leading to guttation. Root pressure is most prominent at night or under conditions of high soil moisture.

147. (D) Requires continuous soil supply or repeated foliar sprays.
Because calcium is immobile in the phloem, it cannot be moved from older leaves to support the growth of new tissues or developing fruits. In agricultural management, this means that a single early application of calcium is often insufficient. To prevent localized deficiencies and related disorders like blossom-end rot, plants require a continuous supply of calcium from the soil throughout the growing season, or repeated foliar sprays directly on expanding tissues.

148. (B) Apoplastic diffusion from tracheids then mesophyll uptake.
Xylem unloading is the process by which nutrients transported from the roots are released into the leaf tissues. In expanding sink leaves, this typically occurs via apoplastic diffusion. Once the nutrients exit the dead tracheids and enter the cell wall space, they are taken up by the plasma membranes of the surrounding mesophyll cells. This allows the developing leaf to acquire the minerals needed for growth and photosynthesis.

149. (C) Humidity level where salt absorbs water to become liquid.
The Point of Deliquescence is a critical physical property of the salts used in foliar fertilizers. It refers to the specific relative humidity above which a dry salt particle will absorb enough moisture from the air to dissolve and form a liquid solution. Maintaining the environmental humidity above the POD of the fertilizer salt is essential for ensuring that the nutrients remain in a dissolved, absorbable state on the leaf surface.

150. (A) Urea facilitates cuticular penetration by increasing the permeability of the cuticle.
Adding urea to foliar iron sprays is a common practice to enhance iron absorption. Urea is a small, uncharged molecule that can penetrate the leaf cuticle relatively easily. As it moves through the waxy barrier, it is thought to increase the overall permeability of the cuticle, facilitating the co-transport or subsequent entry of the iron ions. This synergistic effect makes the foliar treatment more effective at correcting iron deficiencies.

151. (A) Become more alkaline due to OH^- or HCO^{3-} efflux.
The form of nitrogen taken up by plant roots has a significant impact on the pH of the rhizosphere. When plants absorb negatively charged nitrate ions, they must maintain electrical balance by excreting hydroxyl or bicarbonate ions into the surrounding soil. This process leads to an increase in the pH of the rhizosphere, making it more alkaline. This change in pH can influence the availability of other essential nutrients and microorganisms.

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152. (C) Actively fixing atmospheric nitrogen gas.
Root mucilage is a complex mixture of polysaccharides secreted by the root cap that serves several important functions in the rhizosphere. It lubricates the root tip as it grows through the soil, protects the root from drying out, and can bind heavy metals to reduce their toxicity. However, mucilage does not have the capacity to actively fix atmospheric nitrogen gas, a biological process strictly limited to specific bacteria and specialized prokaryotes.

153. (A) Orthophosphate ($H_2PO_4^-$ / HPO_4^{2-}).
Plants primarily absorb phosphorus from the soil solution in the form of inorganic orthophosphate ions, specifically dihydrogen phosphate and hydrogen phosphate. The relative abundance of these two forms depends on the soil pH. Although phosphorus is often present in large amounts, its low solubility and mobility make it difficult for roots to acquire. The symbiotic association with Arbuscular Mycorrhizal Fungi significantly enhances the uptake of these ions.

154. (B) Enhanced tolerance to drought and root pathogens.
Beyond improving nutrient acquisition, particularly phosphorus, colonization by

roots and functions within the cell exclusively as a monovalent cation. Unlike nitrogen or phosphorus, which are incorporated into complex organic molecules, potassium remains in its ionic form. It plays a critical role in osmoregulation, enzyme activation, and maintaining electrical balance. Other macronutrients like calcium and magnesium are taken up as divalent cations, while sulfur is an anion.

172. (C) Critical nutrient concentration.
The critical nutrient concentration marks the transition zone on a plant's growth response curve. It sits between the range of hidden hunger, where growth is limited without obvious symptoms, and the range of luxury consumption, where further nutrient uptake does not increase yield. Maintaining tissue nutrient levels at this critical point ensures that the plant has just enough resources for maximum growth. It is an essential value for agronomists interpreting analysis results.

173. (A) Spindle fiber formation and cell division.
Calcium is absolutely essential for the growth of meristematic tissues because of its role in cell division. It is required for the proper formation and function of spindle fibers during mitosis and for the synthesis of new cell walls during cytokinesis. A deficiency of calcium quickly leads to the failure of growing tips, resulting in stunted roots and shoots. This requirement for continuous cell division explains why calcium must be constantly supplied to growing points.

174. (D) Undissociated boric acid (H_3BO_3).
Boron is unique among essential micronutrients because at the typical pH of most soil solutions, it exists primarily as undissociated boric acid. This small, uncharged molecule can be absorbed by roots through passive diffusion across the lipid bilayer or through specialized channel proteins such as certain aquaporin isoforms. Once inside, boron is involved in several key processes, including cell wall structural integrity and the development of reproductive organs, such as pollen tubes.

175. (A) P-3, Q-4, R-1, S-2.
Iron deficiency is characterized by interveinal chlorosis on the youngest leaves, while zinc deficiency often leads to "little leaf" and shortened internodes. Molybdenum deficiency causes "whiptail" disease in cauliflower, reflecting its role in nitrogen metabolism. Finally, calcium deficiency results in localized disorders like blossom-end rot in tomatoes. Each of these symptoms provides a diagnostic clue used to identify specific nutrient shortages in the field and implement targeted fertilization strategies.

176. (D) Reducing aluminum toxicity while increasing phosphorus.
The primary goal of liming acidic soils is to raise the soil pH to a level that is more favorable for growth. This process helps to reduce the solubility and toxicity of aluminum and manganese, which can severely damage root systems in acidic conditions. Furthermore, increasing pH generally enhances the availability of several essential nutrients, most notably phosphorus and molybdenum, and creates a more hospitable environment for beneficial soil microorganisms and nitrogen-fixing bacteria.

177. (A) Inside cation-anion product equals outside product.
The Donnan equilibrium is a physical principle that describes the distribution of mobile ions across a membrane or within a space containing fixed, non-diffusible charges, such as the root cell wall. At equilibrium, the product of the concentrations of the mobile cations and anions inside the space must equal the product of their concentrations in the external solution. This phenomenon leads to an accumulation of cations and exclusion of anions in the Donnan Free Space.

178. (B) Auxin.
The plant hormone auxin is a key regulator of cell elongation and growth. According to the acid growth hypothesis, auxin activates plasma membrane H^+-ATPases, which pump protons into the cell wall. This acidification of the apoplast activates enzymes that loosen the cell wall structure, allowing expansion due to turgor pressure. This rapid response is essential for various plant movements and developmental processes, demonstrating the link between hormone signaling and membrane transport.

179. (C) Voltage-gated channels.
Voltage-gated channels are a class of ion channels that open or close in response to changes in the electrical potential across the plasma membrane. They play a critical role in various physiological processes, including propagation of electrical

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or improper nutrient balance. Such crops take up large fertilizer amounts without yield increase.

163. (B) Leaching, denitrification, and volatilization.
The recovery efficiency of nitrogen fertilizer is often low because significant amounts of applied nitrogen are lost from the soil-plant system. Major loss pathways include leaching of nitrate into groundwater, denitrification of nitrate into nitrogen gases in anaerobic soils, and volatilization of ammonia from the soil surface, especially in alkaline conditions. These losses represent an economic drain for farmers and can have negative environmental consequences, such as water pollution.

164. (C) Nitrogen remobilization and Use Efficiency.
Overexpressing the cytosolic isoform of glutamine synthetase (GS1) is a major target for biotechnological efforts to improve Nitrogen Use Efficiency in crops. GS1 is particularly important for the remobilization of nitrogen from senescing leaves to the developing grains or other sink tissues. By enhancing the activity of this enzyme, researchers hope to increase the amount of nitrogen that is successfully transferred to the harvestable portion, improving yield.

165. (A) Both A and R are true and R is the correct explanation of A.
NRT1.1 is a remarkable dual-affinity nitrate transporter that can function in both high-affinity and low-affinity ranges depending on its phosphorylation state. By increasing its expression, plants can potentially enhance their total nitrogen uptake across a wide range of external concentrations. NRT1.1 also serves as a nitrate sensor, or transceptor, that triggers various developmental and physiological responses to nitrogen availability. This versatility makes it a key target for improving efficiency.

166. (C) Vacuole.
One of the primary cellular mechanisms that allows hyperaccumulator plants to tolerate extremely high concentrations of heavy metals is the sequestration of these toxic ions into the central vacuole. By moving the metals across the tonoplast and away from the sensitive metabolic processes in the cytoplasm and organelles, the plant can prevent widespread damage. This sequestration is often mediated by specialized transport proteins and the presence of chelating molecules.

167. (B) Phosphate.
Arsenate is a chemical analogue of phosphate and can be taken up by plant roots using the same high-affinity phosphate transport systems. Once inside the cell, arsenate can interfere with vital metabolic processes, such as phosphorylation reactions and ATP synthesis, by substituting for phosphate. This competition is a major reason why arsenic is highly toxic to most plants and why high soil phosphate levels can sometimes reduce arsenic absorption by a crop.

168. (C) Phytovolatilization / Hydraulic control.
Using deep-rooted trees to manage contaminated groundwater is a phytoremediation strategy that combines hydraulic control with potential phytovolatilization or degradation. The large root systems of these trees act as biological pumps, drawing up significant volumes of water and preventing the spread of the contaminant plume. Some contaminants may be transpired through the leaves or broken down by microbes in the rhizosphere, effectively treating the water while maintaining balance.

169. (A) 0.1% to 1% (e.g., >1000 mg/kg for Ni, >10,000 mg/kg for Zn).
A true metal hyperaccumulator is defined by its extraordinary ability to concentrate specific metals in its dried shoot tissue at levels that would be highly toxic to most other plant species. These threshold concentrations are generally set at 0.1 to 1 percent of the dry weight, depending on the metal. For example, a nickel hyperaccumulator must contain more than 1000 mg/kg, while a zinc hyperaccumulator must exceed 10,000 mg/kg.

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170. (B) Hydroponics (solution culture).
Julius von Sachs was a pioneer in plant physiology who developed the technique of hydroponics, also known as solution culture. By growing plants in carefully defined mineral solutions without soil, he was able to identify the essential elements required for plant growth and development. This method allows researchers to precisely control the availability of each nutrient and observe the specific symptoms that occur when one is missing. Hydroponics remains a fundamental study tool.

171. (B) Potassium.
Among the essential macronutrients, potassium is unique because it is absorbed by plant

essential for the life cycle and involved in various functions.

120. (C) Silicon
Silicon is a beneficial element that has been shown to enhance salinity tolerance in various plant species. When applied in saline environments, silicon can reduce the uptake of toxic sodium ions or improve the plant's ability to tolerate them within its tissues. It may also enhance water use efficiency and maintain better ionic balance, helping the plant cope with osmotic and ionic stresses from salt.

121. (B) The dilution effect
The dilution effect occurs when a rapid increase in plant biomass, often triggered by the application of a limiting nutrient, happens faster than the plant can absorb more of that nutrient. This leads to a temporary decrease in the tissue concentration of the nutrient, even though its total amount in the plant has increased. This phenomenon is common during early growth stages or sudden favorable conditions.

122. (D) No significant change in yield
In the adequate zone of a nutrient response curve, the plant has sufficient nutrients to meet all its metabolic requirements for maximum growth. Further increases in the tissue concentration of that nutrient do not lead to any significant change in yield or biomass production. This range is characterized by optimal plant performance and healthy development, and it precedes the phase of luxury consumption where nutrients are absorbed.

123. (A) Lignin
Nitrogen is a fundamental component of many essential plant molecules, including all amino acids, nucleotides (DNA and RNA), and the porphyrin ring of chlorophyll. However, it is not a direct constituent of lignin, which is a complex phenolic polymer found in secondary cell walls. Lignin is primarily composed of carbon, hydrogen, and oxygen, providing structural rigidity and water transport capability to the vascular tissues.

124. (B) ATP, forming a Mg-ATP complex required by kinases.
Magnesium is a vital cofactor in many enzymatic reactions, especially those involving the transfer of phosphate groups. It binds to ATP molecules to form a stable Mg-ATP complex, which is the actual substrate for most kinase enzymes. This complex is essential for energy metabolism, DNA replication, and the regulation of various signal transduction pathways. Without sufficient magnesium, vital phosphorylation is severely compromised.

125. (A) Both A and R are true and R is the correct explanation of A.
Potassium is highly mobile within the plant's vascular system, particularly in the phloem. When a deficiency occurs, the plant prioritizes its survival by retranslocating potassium from the older leaves to the younger, actively growing tissues and reproductive organs. Consequently, the first signs of potassium deficiency, such as marginal chlorosis and necrosis, typically appear on the oldest leaves, accurately reflecting the plant's internal management strategy.

126. (D) Nitrogenase and Nitrate Reductase.
Molybdenum is a critical micronutrient required for the function of several essential plant enzymes, most notably dinitrogenase and nitrate reductase. dinitrogenase is responsible for biological nitrogen fixation in legumes, while nitrate reductase catalyzes the first step of nitrate assimilation in all plants. Because of its role in these key pathways, molybdenum deficiency often results in symptoms that resemble nitrogen deficiency, such as chlorosis.

127. (A) Molybdenum
Molybdenum is essential for the metabolism of nitrogen in many legumes that transport fixed nitrogen in the form of ureide compounds, such as allantoin and allantoic acid. It is a cofactor for the enzyme xanthine dehydrogenase, which is involved in the pathway leading to ureide synthesis. Proper molybdenum supply is therefore necessary for the efficient transport and utilization of nitrogen products from the root nodules.

128. (C) Chloroplast stroma
In C3 plants, the enzyme carbonic anhydrase is predominantly found in the chloroplast stroma. This zinc-containing enzyme catalyzes the rapid interconversion of carbon dioxide and bicarbonate, helping to maintain an adequate supply of CO_2 for the Rubisco enzyme during photosynthesis. Carbonic anhydrase plays a vital role in increasing the efficiency of carbon

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signals, regulation of stomatal movements, and coordination of nutrient uptake. By sensing membrane voltage, these channels allow plants to rapidly adjust ionic fluxes and respond to environmental stimuli or internal signals with high precision and speed.

180. (B) Increase the apparent Km without changing the Vmax.
In the context of Michaelis-Menten kinetics for ion uptake, a competitive inhibitor is a substance that competes with the nutrient ion for the same binding site on the transport protein. This competition increases the apparent K_m, meaning a higher concentration of the nutrient is required to achieve half the maximum transport rate. However, if the nutrient concentration is high enough, it can still reach the original maximum velocity, so the $V_{\max}$ remains unchanged.

181. (A) Desmotubule.
Plasmodesmata are complex channels that connect the cytoplasm of adjacent plant cells, facilitating communication and transport. They are lined by the plasma membrane and contain a central, tightly constricted tubular structure called the desmotubule. The desmotubule is derived from and is continuous with the endoplasmic reticulum of the two connected cells. The space between the desmotubule and the plasma membrane, known as the cytoplasmic sleeve, is where most symplastic transport occurs.

182. (A) H^+-ATPases located in the plasma membrane of adjacent xylem parenchyma cells.
The active loading of solutes into the root xylem is a critical step for long-distance transport. This process is primarily driven by the electrochemical gradient generated by H^+-ATPases located on the plasma membranes of the living xylem parenchyma cells. These pumps create a proton motive force that powers secondary active transport or facilitates passive diffusion into the dead tracheary elements. This coordination ensures efficient delivery of nutrients to the shoot tissue.

183. (C) Pressure-flow hypothesis (Münch hypothesis).
The pressure-flow hypothesis, also known as the Münch hypothesis, is the most widely accepted explanation for the long-distance movement of sap in the phloem. It states that transport is driven by an osmotically generated pressure gradient between source and sink. High sugar concentrations at the source lead to water influx and high turgor pressure, while unloading at the sink leads to water efflux. This difference causes bulk flow of sap through sieve tubes.

184. (A) To keep nutrient salts (especially transition metals) in soluble, unprecipitated forms.
When preparing foliar nutritional sprays, it is important to maintain the solution at a slightly acidic pH, typically between 5.0 and 6.0. This range is optimal for keeping many essential nutrient salts, particularly transition metals like iron, zinc, and manganese, in their soluble and unprecipitated forms. If the solution becomes too alkaline, these nutrients can react to form insoluble hydroxides or carbonates on the leaf surface, reducing the overall effectiveness of treatment.

185. (A) III and V.
The rhizosphere is a highly dynamic zone where roots significantly influence local soil through exudates, which can account for up to twenty percent of fixed carbon and support large microbial populations. However, the rhizosphere does not extend to a fixed distance like one meter; it is much smaller, typically only a few millimeters. Furthermore, roots can indeed alter rhizosphere pH depending on the type of ions they absorb, such as nitrate or ammonium.

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186. (B) Bacteroids.
Once inside the cells of a legume root nodule, Rhizobium bacteria undergo a significant transformation into specialized, non-dividing forms called bacteroids. These bacteroids are enclosed within a plant-derived membrane called the peribacteroid membrane, forming a functional unit known as the symbiosome. Within this protected environment, bacteroids express the nitrogenase enzyme complex and carry out the essential process of biological nitrogen fixation, converting atmospheric N_2 into ammonia for the host plant.

187. (C) 8.
The reduction of one molecule of nitrogen gas to two molecules of ammonia is a complex chemical reaction that requires a total of eight high-energy electrons. Six of these electrons are used directly for the reduction of nitrogen, while the remaining two are used for the obligatory production of one molecule of hydrogen gas. This electron requirement, combined with the

high demand for ATP, makes biological nitrogen fixation one of the most metabolically expensive processes.

188. (C) Roots.
While many herbaceous plants reduce the majority of their absorbed nitrate in the leaves, many temperate species and woody plants perform a significant portion of this process within their root systems. The nitrate is reduced to ammonium and subsequently incorporated into organic nitrogen compounds, such as amino acids or amides, before being transported through the xylem to the rest of the plant. This spatial division is an important physiological adaptation that can vary.

189. (A) Cysteine.
In the biosynthetic pathway for the essential amino acid methionine, the sulfur atom is directly donated by another sulfur-containing amino acid, cysteine. This process involves several enzymatic steps, including the formation of cystathionine and homocysteine as intermediates. Cysteine itself is the first stable organic sulfur compound formed during sulfate assimilation. This close relationship between the two amino acids ensures that the plant can efficiently manage sulfur resources to meet requirements for protein synthesis.

190. (B) In multiple split doses synchronized with critical crop growth stages.
To maximize Nitrogen Use Efficiency and minimize environmental losses, modern agronomic practices emphasize the application of nitrogen fertilizers in multiple split doses. These applications are carefully timed to coincide with periods of peak nitrogen demand during critical crop growth stages, such as tillering or flowering. This approach ensures that a high proportion of applied nitrogen is actually taken up, reducing risks of leaching, denitrification, and volatilization while supporting optimal yield development.

191. (B) Phosphate starvation.
The expression of genes in the PHT1 family, which encode high-affinity phosphate transporters in plant roots, is robustly induced under conditions of phosphate starvation. This physiological response increases the root's capacity for phosphorus acquisition from the soil when it is most needed. The regulation of these genes is part of a complex signal transduction network that allows the plant to sense its internal phosphorus status and adjust its transport machinery accordingly to survive.

192. (C) Sulfhydryl (-SH) groups.
Toxic heavy metals like lead and cadmium often exert their damaging effects by binding to specific functional groups on plant enzymes and proteins. They have an especially high affinity for sulfhydryl groups, which are critical for the structure and catalytic activity of many essential enzymes. By binding to these groups, heavy metals can irreversibly inactivate the enzymes, disrupting vital metabolic pathways such as photosynthesis, respiration, and nitrogen assimilation, ultimately leading to severe growth inhibition.

193. (A) Phytostabilization.
Phytostabilization is a phytoremediation technique that focuses on immobilizing toxic heavy metals within the soil to prevent their spread and reduce environmental risk. This is achieved by using specific plant species that can convert mobile metal ions into highly insoluble and inert forms, either through chemical reactions in the rhizosphere or by sequestration within root tissues. By stabilizing the contaminants in place, this strategy prevents them from leaching into groundwater or other ecosystem organisms.

194. (B) Tomato (Lycopersicon esculentum).
Arnon and Stout established their classical criteria for the essentiality of plant nutrients based on extensive experiments primarily using the tomato plant. This species was chosen for its rapid growth, ease of cultivation in solution culture, and its ability to show clear and distinct deficiency symptoms for various elements. Their work with tomatoes provided the foundational knowledge for our modern understanding of plant nutrition and helped define the specific roles of macronutrients and micronutrients.

195. (C) Molybdenum.
Molybdenum is an essential micronutrient required in significantly higher quantities by leguminous plants when they are actively engaged in biological nitrogen fixation. This is because molybdenum is a core component of the nitrogenase enzyme complex, which catalyzes the reduction of atmospheric nitrogen in the root nodules. Without sufficient molybdenum,

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the symbiotic relationship cannot function effectively, even if other nutrients are abundant. This specific requirement makes molybdenum fertilization important for achieving high yields in legume crops.

196. (B) Directly reflects nutrient absorption and assimilation.
In diagnosing the nutrient status of a crop, particularly for identifying hidden hunger, plant tissue analysis is often preferred over soil testing. This is because tissue analysis directly reflects the amount of nutrients that the plant has actually absorbed and successfully assimilated from its environment. Soil testing only indicates the potential availability of nutrients and cannot account for factors such as root health, soil moisture, and environmental conditions that restrict ability to take up minerals.

197. (C) Calcium and Magnesium.
High concentrations of potassium in the soil solution can have an antagonistic effect on the absorption of other essential cations by plant roots. Specifically, excessive potassium can significantly suppress the uptake of calcium and magnesium. This competitive inhibition occurs because these ions often compete for the same transport sites or are influenced by the overall electrical balance of the root cells. Maintaining a proper ratio between these three macronutrients is critical for preventing physiological imbalances.

198. (A) Pollen tube elongation and germination.
Boron is an essential micronutrient that is particularly critical during the reproductive stage of plant development. It plays an indispensable role in the germination of pollen grains and the subsequent elongation of the pollen tube through the style to reach the ovary. Without sufficient boron, fertilization cannot occur, leading to poor seed and fruit set. This specific requirement makes boron availability a major factor in determining final yield and quality of many flowering crops.

199. (B) The element is remobilized from older leaves to support new growth.
Magnesium deficiency in plants is characterized by a hallmark pattern of interveinal chlorosis on older leaves. This occurs because magnesium is a highly mobile element within the plant's vascular system. When the soil supply is inadequate, the plant remobilizes magnesium from older leaves and moves it to the younger, actively growing tissues and reproductive organs to ensure their survival. This internal relocation of resources is a common physiological strategy for managing nutrient stress.

200. (C) Denitrification.
In waterlogged or anaerobic soil conditions, nitrate is rapidly lost from the soil profile through the biological process of denitrification. This process is carried out by specialized soil bacteria that use nitrate as an alternative electron acceptor in the absence of oxygen. The bacteria reduce the nitrate into gaseous forms of nitrogen, such as nitrous oxide and molecular nitrogen, which then escape into the atmosphere. Denitrification is a major cause of nitrogen fertilizer inefficiency.

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201. (B) Passive diffusion into the Apparent Free Space (AFS).
When a plant root is placed in a salt solution, the rapid initial phase of ion uptake is primarily due to the passive diffusion of ions into the Apparent Free Space. This extracellular volume, which includes the cell walls and intercellular spaces of the root cortex, is readily accessible and does not require expenditure of metabolic energy. This process is fast and reversible, as ions in the AFS can easily exchange with the external solution, preceding active transport.

202. (A) Protons (H^+).
The active loading of sucrose into the phloem companion cells is a critical process for long-distance transport. This secondary active transport is mediated by specialized symporter proteins that couple the inward movement of sucrose with the thermodynamically favorable influx of protons. The proton gradient that drives this process is generated by the activity of plasma membrane H^+-ATPases. This mechanism allows plants to concentrate sucrose in sieve tubes against a steep gradient, creating pressure flow.

203. (C) Guard cell swelling and stomatal opening.
The opening of stomata is triggered by the influx of potassium ions into the guard cells through specialized inwardly rectifying potassium channels. As the potassium concentration increases, it lowers the osmotic potential, causing water to enter by osmosis. This leads to an increase in turgor pressure and causes the guard cells to swell and bow outward, creating

walls, starch for energy storage, and the carbon skeletons of proteins and lipids. Their abundance and central role in building the physical structure distinguish them from other nutrients.

220. (D) III, V, IV, I, II.
The growth response of a plant to increasing nutrient concentrations follows a specific sequence. It begins with severe deficiency, where growth is severely limited and symptoms are visible. This is followed by hidden hunger, where growth is still restricted but without obvious symptoms. The plant then enters the adequate zone of maximum growth. Further uptake leads to luxury consumption without additional yield gain. Finally, if concentrations continues to rise, the plant reaches the toxicity phase.

221. (A) ATP.
Phosphorus is a vital component of the universal energy carrier ATP. It forms high-energy pyrophosphate bonds that store the energy released during photosynthesis and respiration. When these bonds are broken, the energy is released to power various metabolic processes, including synthesis of macromolecules and active transport of ions. The central role of phosphorus in ATP highlights its indispensable importance for all living organisms, as it is the key molecule for energy transfer and storage in metabolism.

222. (B) Urea.
Nickel is an essential micronutrient required for the activity of the enzyme urease. This enzyme catalyzes the hydrolysis of urea into ammonia and carbon dioxide. Without sufficient nickel, plants cannot effectively break down urea, leading to its toxic accumulation in the tissues. This accumulation can cause necrotic lesions, particularly at the leaf tips, and severely impair nitrogen metabolism. Although nickel is needed in very small amounts, its role in preventing urea toxicity is vital for plant health.

223. (D) Copper.
"Reclamation disease" is a significant physiological disorder that often affects cereal crops grown on newly reclaimed peat or organic soils. This condition is caused by a severe deficiency of copper, which becomes strongly bound to high levels of organic matter in these soils, making it unavailable to plants. The deficiency leads to symptoms such as chlorosis of young leaves and failure of heads to fill. Correcting this disease requires the application of copper fertilizers to ensure adequate nutrition.

224. (C) Calcium.
In highly alkaline soils with a pH above 8.0, the availability of phosphorus is drastically reduced. This occurs because phosphate ions react with abundant calcium ions to form various insoluble calcium phosphate minerals, such as hydroxyapatite. These precipitates are not easily absorbed by plant roots, making phosphorus a major limiting factor for crop productivity in calcareous environments. Managing phosphorus fertility in these soils often requires specialized fertilizers or strategies to improve solubility and uptake by roots.

225. (A) II, III, and V.
Passive ion absorption is a physical process that occurs without direct expenditure of metabolic energy. Ions move into the Water Free Space by simple diffusion and are influenced by fixed negative charges in the Donnan Free Space. This process is characterized by being very rapid and reversible, and it is not inhibited by metabolic poisons like cyanide, which only affect active transport processes. Understanding these passive mechanisms is essential for modeling initial steps of nutrient acquisition by root systems.

226. (D) Secondary active transport and ATP synthesis (in organelles).
The proton motive force generated across membranes is a powerful form of stored energy. In plants, it is used directly to drive the secondary active transport of various ions and solutes, such as nitrate, phosphate, and sucrose, via symporters and antiporters. Furthermore, the PMF is the primary driver for ATP synthesis in the mitochondria and chloroplasts, where the flow of protons through ATP synthase complexes provides the energy for phosphorylation. This energy source is central to coordination.

227. (C) Must undergo time-consuming conformational changes.
Carrier proteins exhibit saturation kinetics similar to enzymes because the process of transporting a solute across the membrane involves several time-consuming steps. A carrier must bind the solute, undergo a significant conformational change to move it across the lipid bilayer, and then release it on the other side before it can bind another molecule. This requirement for

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reduced nodule formation and lower nitrogenase activity during growth.

212. (C) Deamination of glutamate during carbon starvation or senescence.
Although glutamate dehydrogenase (GDH) is capable of incorporating ammonium into organic molecules, its primary role in higher plants is now thought to be the reverse reaction. It is particularly important for deamination of glutamate to produce alpha-ketoglutarate and ammonium during periods of carbon starvation or senescence. This process helps provide carbon skeletons for the TCA cycle and recycle nitrogen from old tissues. While GDH can supplement the GS-GOGAT pathway, it is not the main route.

213. (A) Reactive oxygen species (ROS) and heavy metals.
Glutathione is a vital sulfur-containing tripeptide that plays a central role in protecting plants from various environmental stresses. It acts as a powerful antioxidant, scavenging reactive oxygen species produced during photosynthesis, respiration, and in response to biotic and abiotic challenges. Furthermore, glutathione is the precursor for the synthesis of phytochelatins, which are essential for chelating and detoxifying heavy metals like cadmium and lead. Its high reactivity makes it key for defense.

214. (B) Nitrogen.
SPAD chlorophyll meters are widely used in precision agriculture to provide a rapid and non-destructive assessment of the nitrogen status of a crop. Because nitrogen is a core component of the chlorophyll molecule, the leaf's chlorophyll content is highly correlated with its overall nitrogen concentration. By measuring light transmittance through the leaf, SPAD meters give farmers real-time information used to make informed decisions about fertilizer application, helping to optimize nitrogen use efficiency and yield.

215. (C) Transceptor sensing (e.g., NRT1.1) → Uptake via NRT → Nitrate reduction → Amino acid synthesis.
The process of nitrate utilization in plant roots begins with sensing, often mediated by the transceptor NRT1.1, which detects nitrate in the soil. This sensing triggers the subsequent uptake of nitrate through various NRT transporter proteins. Once inside the cell, nitrate is reduced to nitrite and then to ammonium. Finally, the ammonium is assimilated into organic compounds through the GS-GOGAT pathway for amino acid synthesis. This coordinated sequence allows plants to utilize available nitrogen resources.

216. (C) Vacuoles of the leaf fronds.
The fern Pteris vittata is a well-known arsenic hyperaccumulator that can survive in highly contaminated soils. Its tolerance mechanism involves the rapid uptake of arsenate from the soil, which is then quickly reduced to arsenite within the plant. This arsenite is subsequently translocated to the shoots and actively sequestered into the vacuoles of the leaf fronds. By storing toxic arsenic in the vacuoles of harvestable tissues, the plant prevents interference with vital metabolic processes.

217. (A) Extremely slow growth rate and low biomass production.
When choosing a plant species for phytoextraction, an extremely slow growth rate and low biomass production are highly disadvantageous. To be effective, a phytoextraction plant must be able to remove significant amounts of heavy metals from the soil in a reasonable amount of time. This requires not only high tolerance and the ability to hyperaccumulate the target metal but also a rapid growth rate and the capacity to produce a large amount of harvestable shoot biomass.

218. (D) Magnesium in the chlorophyll molecule.
According to the criteria of essentiality established by Arnon and Stout, an element is considered essential if it is a direct and necessary component of a molecule that is vital for the plant's life. Magnesium perfectly exemplifies this criterion because it is the central atom in the chlorophyll molecule, which is absolutely required for photosynthesis. Without magnesium, the plant cannot form chlorophyll or produce the carbohydrates needed for growth and reproduction, clearly demonstrating its indispensable role.

219. (B) C, H, O.
Carbon, hydrogen, and oxygen are categorized as structural elements because they form the fundamental building blocks of almost all plant tissues and organic molecules. Together, they constitute approximately ninety-five percent of the total dry matter of a plant. These elements are the primary components of cellulose in cell

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the stomatal pore. This rapid and reversible process is essential for regulating gas exchange and transpiration in plants.

204. (C) Operates against gradients and requires metabolic energy.
The High-Affinity Transport System for potassium uptake in plant roots is a specialized mechanism that allows for absorption even when external concentrations are extremely low. Unlike the low-affinity system, the HATS typically operates against a steep electrochemical gradient and therefore requires the expenditure of metabolic energy. It is often mediated by specific high-affinity transporters and is robustly regulated by internal potassium status, ensuring plants can acquire this essential nutrient from depleted soil solutions.

205. (B) Epidermis → Cortex → Endodermis → Pericycle → Xylem.
When moving from the soil solution to the root xylem via the symplastic pathway, an ion must traverse several distinct tissue layers in a specific sequence. It first enters the epidermis, then moves through the multiple layers of the root cortex. Upon reaching the endodermis, it passes through to the pericycle, and finally, it is loaded into the xylem vessels. This pathway, occurring within the interconnected living cytoplasm, allows the plant to carefully regulate absorbed nutrients.

206. (B) Epidermis.
The pericycle is a specialized layer of cells in the plant root that is located immediately inside the endodermis and just outside the vascular tissues of the xylem and phloem. It forms the outermost layer of the stele or vascular cylinder. The pericycle is a highly important tissue because it is the site of lateral root initiation and plays a key role in secondary growth. It also serves as a critical interface for radial transport of nutrients.

207. (C) Relying on root pressure to refill embolized vessels at night.
Xylem transport can be disrupted by cavitation, the formation of air bubbles that block the flow of water. Plants can overcome small cavitations, particularly in herbaceous species, by relying on root pressure to refill the embolized vessels during the night. When transpiration is low and soil moisture is high, the positive pressure generated by active accumulation of ions can force air bubbles back into solution. This process helps restore the continuity of the water column.

208. (C) Surface tension.
Surfactants are commonly added to foliar fertilizer solutions to improve their wetting and spreading properties on the leaf surface. They work by significantly reducing the surface tension of the aqueous solution, which allows the droplets to flatten and cover a larger area of the leaf. This increased contact area, combined with a lower contact angle, facilitates penetration of nutrients through the hydrophobic cuticle and stomatal pores, thereby enhancing the overall efficiency of application.

209. (A) Malate and citrate.
Many plant species have evolved resistance to aluminum toxicity in acidic soils by secreting organic acid anions, such as malate and citrate, from their root apices. These anions act as powerful chelators that bind to toxic Al^{3+} ions in the rhizosphere, forming stable and non-toxic complexes. By preventing aluminum from entering the root tip or interfering with cellular processes, this mechanism allows plants to maintain root growth and nutrient uptake in chemically hostile environments.

210. (B) II, IV, I, III.
The establishment of Arbuscular Mycorrhizal symbiosis begins with the host root secreting strigolactones, which signal nearby fungal spores to germinate and branch. The germinating hyphae then form a hyphopodium on the root surface to initiate penetration. Once inside the root, the fungus grows between and into cortical cells, eventually forming highly branched arbuscules that are primary sites for nutrient exchange. This carefully coordinated sequence of events ensures the successful formation of the association.

211. (B) Downregulate nitrogenase activity and rely on the soil nitrogen.
When a legume crop is provided with a large amount of synthetic nitrogen fertilizer, it will typically downregulate its own biological nitrogen fixation. This is because nitrogen fixation is a very energy-expensive process. If an easily available source of inorganic nitrogen, such as nitrate or ammonium, is present in the soil, the plant will prioritize absorbing that instead of supporting Rhizobium bacteria. This results in

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rearrangement limits the maximum rate of transport, regardless of how high the external solute concentration becomes. This differs from diffusion through channels.

228. (B) Increasing affinity (low Km) or transporter density.
When plants experience a nutrient deficiency, they often employ various physiological and molecular strategies to compensate for low availability in the soil. One common response is upregulating the expression of genes encoding high-affinity transporters, thereby increasing the density of these proteins in the root cell membranes. Alternatively, the plant may express transporters with a lower K_m, representing a higher affinity. These adaptations improve the root's ability to scavenge the limiting nutrient from the environment under stress.

229. (A) Endodermis.
The continuous apoplastic pathway for movement of water and dissolved solutes through the root cortex is physically interrupted by the Casparian strip. This specialized structural feature is located exclusively within the radial and transverse walls of endodermal cells. By blocking the intercellular spaces and cell wall network, the Casparian strip forces all substances to cross the living plasma membrane of the endodermis to enter the vascular cylinder. This allows plants to exert precise control over minerals translocated.

230. (A) Xylem loading.
After nutrients have traveled through the symplastic pathway across root tissues, they reach the xylem parenchyma cells. The final and crucial step in root nutrient acquisition is xylem loading, which involves the efflux of these ions from living parenchyma cells into dead tracheary elements of the xylem. This process is mediated by specialized transport proteins and is driven by the electrochemical gradient across the parenchyma cell membrane. Once in the xylem, nutrients are ready for long-distance bulk transport.

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CHAPTER 07
Climate and Climate Change

2006

1. Which component of Earth's energy budget describes the fraction of incident solar radiation that is reflected back into space by surfaces such as ice and clouds?
(A) Planetary albedo
(B) Radiative forcing
(C) Sensible heat flux
(D) Latent heat of vaporization

2011

2. Identify the INCORRECT statement regarding the natural greenhouse effect.
(A) It maintains Earth's average surface temperature at approximately 15°C.
(B) Water vapor is the most abundant natural greenhouse gas in the atmosphere.
(C) It is primarily driven by anthropogenic halocarbon emissions.
(D) It involves the absorption of outgoing longwave infrared radiation.

2011

3. What is the fundamental distinction between climate variability and climate change?
(A) Variability involves short-term fluctuations, while change is a long-term shift.
(B) Variability involves natural cycles, while change is purely anthropogenic.
(C) Variability affects precipitation, while change impacts global temperatures.
(D) Variability is calculated over millennia, while change is strictly decadal.

2009

4. Which of the following best defines "weather" as opposed to "climate"?
(A) Decadal shifts in atmospheric circulation patterns across the globe.
(B) The 30-year average of temperature and precipitation for a region.
(C) The long-term integration of planetary albedo fluctuations over time.
(D) The specific state of the atmosphere at a given time and place.

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2002

5. In the context of the Earth's energy budget, what is the primary role of latent heat flux?
(A) Increasing the direct absorption of shortwave solar radiation by the lithosphere.
(B) Transferring surface energy to the atmosphere through water phase changes.
(C) Reflecting incoming solar radiation back to the stratosphere via cloud cover.
(D) Enhancing the sensible heat transfer through dry air convection in the troposphere.

2010

6. Identify the correct statement regarding outgoing longwave radiation (OLR).
(A) It is primarily energy emitted in the ultraviolet spectrum by the lithosphere.
(B) It represents the shortwave energy reflected by the Earth's surface to space.
(C) It is continuously absorbed and re-emitted by gases in the troposphere.
(D) It remains completely unaffected by the concentration of atmospheric CO_2.

2022

7. What is the most relevant mechanism by which the enhanced greenhouse effect alters the Earth's energy budget?
(A) Permanently decreasing the solar constant.
(B) Vastly increasing the planetary albedo.
(C) Accelerating the depletion of ozone.
(D) Positive net radiative forcing at the tropopause.

2006

8. Which factor is considered an internal driver of climate variability rather than an external forcing?
(A) El Niño-Southern Oscillation (ENSO)
(B) Explosive volcanic eruptions
(C) Periodic orbital eccentricity
(D) Solar irradiance fluctuations

2005

9. Which atmospheric layer is primarily responsible for the natural greenhouse effect due to its high concentration of water vapor and CO_2?
(A) Stratosphere

(B) Troposphere
(C) Mesosphere
(D) Thermosphere

2023

10. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).

Assertion (A): Ice core records from Antarctica provide an accurate proxy for historical atmospheric CO_2 concentrations.
Reason (R): The isotopic composition of trapped air bubbles precisely reflects the ambient temperature at the time of snow deposition.
In light of the above statements, choose the correct answer from the options given below:
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2011

11. Which paleoclimatological proxy is most appropriately used to infer historical changes in vegetation and regional climate patterns?
(A) Pollen analysis (Palynology)
(B) Glacial striations
(C) Atmospheric halocarbons
(D) Thermohaline circulation speed

2013

12. Which parameter is directly measured from oceanic sediment layers to estimate historical sea surface temperatures?
(A) Benthic methane hydrate levels in the deep sea.
(B) Annual sedimentary tree-ring equivalent profiles.
(C) Oxygen isotope ratios ($\frac{^{18}O}{^{16}O}$) in foraminifera.
(D) Dissolved organic carbon levels in surface water.

2003

13. Identify the correct pair of paleoclimatic proxy and its primary temporal resolution.
(A) Ice cores : Millions of years
(B) Ocean sediments : Decadal to century scale
(C) Pollen analysis : Daily
(D) Tree rings : Annual

2001

14. Which of the following is NOT a common limitation of using pollen analysis for paleoclimatic reconstruction?
(A) Differential preservation rates of pollen grains
(B) Overrepresentation of wind-pollinated taxa
(C) High susceptibility to modern halocarbon contamination
(D) Challenges in taxonomic identification down to the species level

2011

15. Match the paleoclimatological method in List I with its core target material in List II.
List I: (Method)
P. Dendroclimatology
Q. Palynology
R. Ice core analysis
S. Sedimentology
List II: (Target Material)
1. Spores and micro-gametophytes
2. Trapped air bubbles
3. Foraminifera and varves
4. Annual growth rings
(A) P-4, Q-3, R-2, S-1
(B) P-2, Q-1, R-4, S-3
(C) P-4, Q-1, R-2, S-3
(D) P-1, Q-2, R-3, S-4

2010

16. What is the primary cause of the darker bands in varve sediment layers used for paleoclimatology?
(A) High biological productivity in spring
(B) Deposition of coarse sand during floods
(C) Rapid evaporation of shallow lakes
(D) Winter deposition of fine organic matter and clay

2018

17. By analyzing the ratio of deuterium to hydrogen in ice cores, scientists can directly infer which past environmental variable?
(A) Local precipitation temperature
(B) Stratospheric ozone levels
(C) Soil carbon sequestration rates
(D) Ocean salinity

2014

18. Which statement about ice core paleoclimatology is INCORRECT?
(A) Annual layers can be visually distinguished in the uppermost ice sections.
(B) They provide direct measurements of past greenhouse gas concentrations.
(C) They are exclusively recovered from Arctic

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oceanic sea-ice.
(D) They contain trapped volcanic ash that aids in precise dating.

2014

19. What is the defining characteristic of a "compliant" tree species used in dendroclimatology?
(A) Its annual ring width is highly sensitive to a specific climate variable, such as precipitation.
(B) It exhibits uniform ring width regardless of environmental stress.
(C) Its growth rings lack earlywood and latewood distinctions.
(D) It grows exclusively in tropical rainforests where seasons are indistinguishable.

2024

20. Match the dendroclimatological feature in List I with its physiological significance in List II.
List I: (Feature)
P. Earlywood
Q. Latewood
R. Frost rings
S. False rings
List II: (Significance)
1. Formed during severe unseasonal cold stress
2. Narrow, dense cells formed in late summer
3. Wide, thin-walled cells formed in spring
4. Formed due to temporary mid-season drought
(A) P-1, Q-4, R-2, S-3
(B) P-3, Q-1, R-4, S-2
(C) P-2, Q-3, R-1, S-4
(D) P-3, Q-2, R-1, S-4

2018

21. Which principle forms the basis of cross-dating in dendroclimatology?
(A) Counting the number of rings from the bark to the pith
(B) Matching patterns of wide and narrow rings across multiple trees to ensure exact temporal placement
(C) Measuring the carbon content of the heartwood
(D) Analyzing the density of stomata on fossilized leaves

2017

22. Identify the INCORRECT pair regarding factors influencing tree-ring growth.
(A) Temperature : Dominant limiting factor in subalpine treelines
(B) Precipitation : Dominant limiting factor in semi-arid environments
(C) Solar eclipses : Primary cause of false ring formation
(D) Defoliating insects : Cause of sudden, severe ring narrowing

NODIA

2015

23. What does a high mean sensitivity index in a tree-ring chronology indicate?
(A) The tree is completely unresponsive to environmental changes.
(B) The tree exhibits low inter-annual variability in ring width.
(C) The tree is highly susceptible to pathogenic decay.
(D) The tree exhibits high year-to-year variability, reflecting strong climate responsiveness.

2012

24. Which condition is LEAST likely to produce an identifiable false ring in a tree?
(A) Consistent, uninterrupted optimal growing conditions
(B) A sudden, severe summer drought followed by heavy rain
(C) An unseasonal spring frost damaging the cambium
(D) Temporary defoliation by an insect outbreak in mid-summer

2019

25. The process of removing the biological growth trend (age-related decline in ring width) from raw tree-ring measurements is known as:
(A) Isotopic fractionation
(B) Standardization
(C) Methanogenesis
(D) Radiative forcing

2006

26. Which anatomical feature is most critical for analyzing past hydrological changes in angiosperm tree rings?
(A) Resin duct density
(B) Vessel element size and distribution
(C) Bark thickness
(D) Root nodule formation

2022

27. How does dendroclimatology uniquely contribute to hydrological modeling?
(A) Multi-century reconstructions of drought indices.
(B) Replacing General Circulation Models entirely.
(C) Measuring the current depth of groundwater.

(D) Calculating the exact GWP of atmospheric methane.

2021

28. During photosynthesis, what is the primary cause of carbon isotopic fractionation favoring ^{12}C over ^{13}C?
(A) 12C is significantly heavier and diffuses slower than 13C.
(B) 12C strongly absorbs UV-B radiation.
(C) Rubisco exhibits a kinetic isotope effect, preferentially fixing the lighter $^{12}CO_2$ molecule.
(D) The enzyme Rubisco has a lower activation energy for binding $^{13}CO_2$.

2015

29. Which photosynthetic pathway typically exhibits the most negative stable carbon isotope ratio ($\delta^{13}C$)?
(A) C4 pathway
(B) CAM pathway during severe drought
(C) Bacterial methanogenesis
(D) C3 pathway

2007

30. Consider the following statements regarding stable carbon isotope discrimination:
I. C4 plants exhibit less negative $\delta^{13}C$ values than C3 plants.
II. Phosphoenolpyruvate (PEP) carboxylase discriminates against ^{13}C more strongly than Rubisco.
III. Stomatal closure during drought decreases internal CO_2 concentration, leading to less negative $\delta^{13}C$ in C3 plants.
Which of the above statements is/are correct?
(A) I and II
(B) I and III
(C) II and III
(D) I only

2010

31. What does a sudden positive shift in the $\delta^{13}C$ value of soil organic matter deep in a sediment profile likely infer?
(A) A historical shift from C4 grasslands to C3 forests.
(B) A shift from C3 to C4 dominated vegetation.
(C) A massive increase in volcanic halocarbon emissions.
(D) Continuous growth of C3 species under elevated CO_2.

2018

32. Identify the correct statement about the $\delta^{13}C$ signature of atmospheric CO_2 since the Industrial Revolution.
(A) It has become more positive due to oceanic outgassing.
(B) It has remained stable over the last 200 years.
(C) It has shifted toward heavier isotopes via deforestation.
(D) It has become more negative due to fossil fuel combustion.

2002

33. The measurement of $\frac{^{13}C}{^{12}C}$ ratios in tree rings is primarily utilized as a proxy to determine historical variations in which physiological parameter?
(A) Intrinsic water use efficiency (iWUE).
(B) Seasonal root respiration rates.
(C) Phloem transport velocity.
(D) Photochemical quenching capacity.

2025

34. Which mathematical expression defines the stable carbon isotope ratio ($\delta^{13}C$) relative to a standard?
(A) $\delta^{13}C = \left[\frac{\left(\frac{^{12}C}{^{13}C}\right)_{standard}}{\left(\frac{^{12}C}{^{13}C}\right)_{sample}} + 1\right] \times 100$
(B) $\delta^{13}C = \left[\frac{^{13}C_{standard} - {}^{13}C_{sample}}{^{12}C_{standard}}\right] \times 1000$
(C) $\delta^{13}C = \left[\frac{\left(\frac{^{13}C}{^{12}C}\right)_{sample}}{\left(\frac{^{13}C}{^{12}C}\right)_{standard}} - 1\right] \times 1000$
(D) $\delta^{13}C = \frac{\left[\left(\frac{^{13}C}{^{12}C}\right)_{sample} + \left(\frac{^{13}C}{^{12}C}\right)_{standard}\right]}{1000}$

2016

35. Why do C4 plants exhibit significantly less isotopic discrimination compared to C3 plants?
(A) Internal Rubisco is forced to fix available ^{13}C.
(B) PEP carboxylase has a very high intrinsic discrimination.
(C) They completely lack the Rubisco enzyme.
(D) They fix carbon exclusively during the night.

2012

36. Under elevated atmospheric CO_2 levels without water stress, how does the isotopic discrimination ($\Delta^{13}C$) of a typical C3 plant respond?
(A) It permanently ceases to occur in leaf tissue.

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(B) It decreases as stomatal conductance drops to zero.
(C) It matches the discrimination rate of C4 plants.
(D) It increases due to higher intercellular CO_2 levels.

2006

37. Which of the following is defined as the total energy absorbed by a greenhouse gas over a given timeframe relative to the same mass of CO_2?
(A) Radiative forcing index
(B) Global Warming Potential (GWP)
(C) Atmospheric half-life
(D) Specific heat capacity

2012

38. Based on a 100-year time horizon, identify the correct sequence of major greenhouse gases in order of increasing Global Warming Potential (GWP).
(A) $N_2O < CO_2 < CH_4 < CFC-12$
(B) $CO_2 < CH_4 < N_2O < CFC-12$
(C) $CH_4 < N_2O < CFC-12 < CO_2$
(D) $CO_2 < N_2O < CH_4 < CFC-12$

2006

39. Consider the following statements regarding greenhouse gases:
I. N_2O has an atmospheric lifetime shorter than that of methane.
II. Halocarbons generally possess higher radiative efficiencies than CO_2.
III. Methane is primarily removed from the atmosphere via hydroxyl radical (OH) oxidation.
IV. CO_2 has a highly specific, single atmospheric lifetime of exactly 12 years.
Which of the above statements is/are INCORRECT?
(A) I and III
(B) II and III
(C) I and IV
(D) III and IV

2018

40. Identify the greenhouse gas that relies almost exclusively on stratospheric photolysis for its atmospheric removal.
(A) Nitrous oxide (N_2O)
(B) Methane (CH7)
(C) Carbon dioxide (CO_2)
(D) Tropospheric ozone (O_3)

2008

41. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A): Radiative forcing provides a standardized metric to compare the warming influence of different greenhouse gases.
Reason (R): It measures the net change in the energy balance of the Earth system due to an imposed perturbation.
In light of the above statements, choose the correct answer from the options given below:
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2007

42. What is the primary anthropogenic source of atmospheric nitrous oxide (N_2O)?
(A) Deforestation and biomass burning
(B) Agricultural application of synthetic nitrogen fertilizers
(C) Enteric fermentation in ruminant livestock
(D) Leakage from natural gas pipelines

2011

43. Why do fully fluorinated compounds (PFCs) and sulfur hexafluoride (SF6) have exceptionally high Global Warming Potentials?
(A) Strong window absorption and long lifetimes.
(B) Rapid breakdown by tropospheric OH radicals.
(C) Short lifetimes but massive radiative forcing.
(D) Continuous reactions with ozone producing heat.

2010

44. The concept of "atmospheric window" refers to which specific wavelength range where Earth's outgoing infrared radiation is not strongly absorbed by natural water vapor and CO_2?
(A) 400 to 700 nm
(B) 2 to 5 μm
(C) 8 to 14 μm
(D) 15 to 20 μm

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2007

45. Which metric is most appropriate for evaluating the immediate, short-term climatic impact of an acute methane emission event?
(A) GWP100
(B) Atmospheric carbon sequestration rate
(C) Biogenic volatile organic compound index

(D) GWP20

2010

46. What biological process is directly responsible for methanogenesis in flooded paddy fields?
(A) Aerobic respiration by methanotrophic bacteria
(B) Photochemical reduction of atmospheric CO_2
(C) Anaerobic degradation of organic matter by Archaea
(D) Nitrogen fixation by cyanobacteria

2006

47. Which agricultural practice is most effective in mitigating methane emissions from rice cultivation?
(A) Continuous deep flooding
(B) Mid-season drainage or Alternate Wetting and Drying (AWD)
(C) Heavy application of raw organic manure before planting
(D) Increasing the planting density of C3 rice cultivars

2003

48. Enteric fermentation in livestock primarily produces methane as a byproduct of which specific digestive process?
(A) Pancreatic enzymatic breakdown of lipids.
(B) Aerobic oxidation of proteins in the intestine.
(C) Gastric acid hydrolysis in the abomasum.
(D) Ruminal microbial fermentation of carbohydrates.

2017

49. Consider the following statements regarding agricultural methane emissions:
I. Methanotrophs in paddy soils oxidize a significant portion of produced methane before it reaches the atmosphere.
II. High-tannin forage diets can increase methane emissions from ruminants.
III. Rice plants act as conduits, facilitating methane transport from the soil to the atmosphere via aerenchyma.
IV. Nitrate application in paddy fields generally stimulates methanogenesis.
V. Ionophores in cattle feed can alter ruminal microflora to reduce methanogenesis.
Which of the above statements is/are correct?
(A) I, III and V
(B) II, III and IV
(C) I, II and IV
(D) III, IV and V

2002

50. What is the primary role of the aerenchyma tissue in rice plants concerning methane dynamics?
(A) It actively synthesizes methane from structural cellulose.
(B) It securely stores methane within the stems until harvest.
(C) It acts as a passive pathway for soil methane release.
(D) It converts methane into CO_2 before it leaves the plant.

2014

51. Which soil condition strictly inhibits the activity of methanogenic archaea in paddy fields?
(A) High oxygen concentration (positive redox potential)
(B) Highly negative redox potential (-200 mV)
(C) High organic matter availability
(D) Neutral pH ranges

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2002

52. Which dietary intervention is a proven mitigation strategy for reducing enteric methane production in cattle?
(A) Feeding low-quality, high-lignin forage.
(B) Eliminating all dietary lipids from the rumen.
(C) Feeding exclusively non-protein nitrogen (NPN).
(D) Supplementing the diet with 3-NOP or red seaweed.

2013

53. How does the application of sulfate fertilizers generally influence methane production in flooded soils?
(A) It rapidly enhances methane production by acting as a direct substrate for methanogenesis.
(B) It reduces methane production because sulfate-reducing bacteria outcompete methanogens for substrates.
(C) It causes the immediate death of all methanotrophic bacteria.
(D) It has absolutely no effect on soil redox potential or methane fluxes.

2015

54. Which is considered a disadvantage of strictly implementing mid-season drainage to mitigate methane in paddy fields?
(A) It substantially increases the global warming potential.
(B) It causes complete failure of aerenchyma formation.

content.
(C) Delayed maturity leading to unseasonal frost damage.
(D) Increased synthesis of amylose relative to amylopectin.

2011

105. "Chalkiness" in rice grains, which significantly degrades milling quality, is primarily induced by:
(A) Extremely low atmospheric CO_2 during tillering
(B) Elevated temperatures during the grain-filling stage disrupting starch packing
(C) Flooding stress during seedling emergence
(D) Application of excessive sulfur fertilizers

2001

106. How does acute heat stress specifically disrupt the process of anthesis?
(A) By forcing the immediate abscission of all sepals.
(B) By inhibiting lodicule swelling, keeping flowers closed.
(C) By turning petals green to perform photosynthesis.
(D) By causing an overproduction of fertile ovules.

2004

107. Which component of the pollen grain makes it highly susceptible to dehydration and loss of viability under high-temperature stress?
(A) The lack of robust heat-shock protein synthesis capabilities in the mature microgametophyte
(B) The tough, sporopollenin-rich exine
(C) Its high concentration of heavily lignified tissues
(D) The excessively thick waxy cuticle layer

2013

108. The term "spikelet sterility" in crops like rice is most directly correlated with temperature extremes occurring during which specific micro-stage?
(A) Late dough stage
(B) Germination
(C) Booting and early anthesis
(D) Panicle initiation

2007

109. What is a common adaptive phenological shift observed in wild plant species experiencing progressively warmer regional climates?
(A) Delaying flowering to late winter
(B) Completely ceasing to produce reproductive organs
(C) Synchronizing flowering precisely with solar eclipses
(D) Advancing the date of bud burst and spring flowering

2013

110. Which agronomic impact is uniquely associated with reduced grain-filling duration caused by terminal heat stress?
(A) Increased grain starch density
(B) Enhanced biofortification of zinc
(C) Shriveled, low-test-weight grains
(D) Delayed leaf senescence

2016

111. Consider the following statements regarding the interactive effects of elevated CO_2 and high temperature on plant respiration:
I. High temperatures universally decrease the $Q_{\{10\}}$ of dark respiration.
II. Elevated CO_2 can sometimes ameliorate the negative impacts of moderate heat stress by increasing resource availability.
III. Combined high CO_2 and high temperature strongly accelerate phenological development, often shortening the crop life cycle.
Which of the above statements is/are correct?
(A) I and II
(B) I and III
(C) II and III
(D) I, II and III

2021

112. When plants are exposed simultaneously to elevated CO_2 and high temperature, how does the optimal temperature for net photosynthesis typically behave?
(A) It shifts to a significantly lower temperature.
(B) It remains rigidly fixed at 25°C at all times.
(C) It disappears entirely, making the rate constant.
(D) It shifts higher due to suppressed photorespiration.

2024

113. Under interactive climate change scenarios, the phenomenon of "phenological acceleration" primarily results in:
(A) A shortened life cycle, reducing biomass accumulation.
(B) A prolonged vegetative stage yielding massive biomass.
(C) The complete reversal of the aging process in tissue.

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(C) Downscaling
(D) Atmospheric normalization

2012

63. How do Coupled Model Intercomparison Projects (CMIP) enhance the reliability of global warming predictions?
(A) By legally enforcing the RCP 2.6 scenario globally
(B) By systematically evaluating and comparing the performance of various GCMs under standardized conditions
(C) By mandating the use of a single, universal climate model
(D) By physically measuring temperature changes using satellite radiometry

2009

64. In climate modeling, what is the effect of a positive cloud-radiation feedback?
(A) It stabilizes the climate by increasing planetary albedo.
(B) It causes a net cooling of the troposphere globally.
(C) It removes excess atmospheric methane via oxidation.
(D) It amplifies surface warming by trapping longwave radiation.

2013

65. The "carbon fertilization effect" primarily refers to an increase in net photosynthetic rate resulting from:
(A) Elevated CO_2 reducing photorespiration in C3 plants.
(B) Enhanced application of synthetic carbon fertilizers.
(C) Increased atmospheric methane concentrations.
(D) Elevated temperatures accelerating enzyme kinetics.

2009

66. Why do C4 plants generally show a diminished growth response to elevated CO_2 compared to C3 plants?
(A) C4 plants lack the Rubisco enzyme entirely.
(B) C4 plants close their stomata permanently when CO_2 rises.
(C) The C4 mechanism already saturates Rubisco with CO_2.
(D) Elevated CO_2 aggressively degrades PEP carboxylase.

2021

67. Under elevated CO_2 concentrations, the oxygenase activity of Rubisco in C3 plants is:
(A) Competitively suppressed, favoring carboxylation.
(B) Maximized, leading to higher photorespiration.
(C) Unaffected, because CO_2 and O_2 bind differently.
(D) Completely eliminated, converting C3 into C4 plants.

2014

68. Which kinetic property of Rubisco is directly responsible for the differential responses of C3 and C4 plants to elevated CO_2?
(A) Its inability to bind ribulose-1,5-bisphosphate (RuBP)
(B) Its exclusive localization in the epidermal cells
(C) Its strict requirement for UV-B light activation
(D) Its low affinity (high K_m) for CO_2 relative to ambient atmospheric concentrations

NODIA

2024

69. Consider the following statements regarding the carbon fertilization effect:
I. Acclimation (down-regulation) of photosynthesis often occurs after long-term exposure to elevated CO_2.
II. Elevated CO_2 decreases the optimal temperature for photosynthesis in C3 plants.
III. Carbon fertilization consistently alleviates all nutrient limitations in the soil.
Which of the above statements is/are INCORRECT?
(A) I and II
(B) I and III
(C) I, II and III
(D) II and III

2009

70. Long-term exposure to elevated atmospheric CO_2 frequently leads to photosynthetic acclimation. Which biochemical mechanism primarily drives this down-regulation?
(A) Hyperactivation of photorespiration depleting ATP.
(B) Massive overproduction of leaf nitrogen compounds.
(C) Non-structural carbohydrate buildup repressing Rubisco genes.
(D) Direct inhibition of photosystem II by the CO_2 molecule.

synthesizer.

2006

87. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A): Elevated atmospheric CO_2 generally enhances the protein concentration in wheat grains.
Reason (R): Increased carbon availability stimulates the simultaneous hyper-assimilation of soil nitrate by the root system.
In light of the above statements, choose the correct answer from the options given below:
(A) Both A and R are false.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is false but R is true.
(D) Both A and R are false.

2006

88. Which class of herbivores is most likely to be negatively impacted by the altered tissue composition (increased $C{:}N$ ratio) of plants grown under elevated CO_2?
(A) Leaf-chewing insects due to reduced protein levels.
(B) Carnivorous predators hunting in the canopy.
(C) Phloem-feeding insects such as local aphids.
(D) Nectar-feeding bats and avian pollinators.

2007

89. In source-sink dynamics, which organ typically acts as the primary "source" during the grain-filling stage of a cereal crop?
(A) The developing endosperm
(B) The mature, photosynthetically active flag leaf
(C) The primary apical root
(D) The floral stigma

2003

90. Elevated CO_2 often alters the partitioning of biomass in agricultural crops. Which structural component frequently exhibits an increased allocation of carbon relative to the shoot?
(A) The stamen
(B) The root system
(C) The terminal bud
(D) The petal primordia

2021

91. Identify the micronutrients most frequently reported to suffer statistically significant concentration declines in edible grains (like rice and wheat) under elevated CO_2.
(A) Zinc and Iron
(B) Sodium and Chloride
(C) Molybdenum and Nickel
(D) Cobalt and Silicon

2001

92. At the cellular level, what is the initial, primary physical disruption caused by acute high-temperature stress?
(A) Immediate crystallization of the cellular cytosol.
(B) Irreversible condensation of chromatin into units.
(C) Increased fluidity and permeability of membranes.
(D) Depletion of starch granules within a few seconds.

2011

93. What specific class of molecules is rapidly synthesized by plant cells to prevent protein denaturation and aggregation during heat stress?
(A) Phytoalexins
(B) Gibberellic acids
(C) Xanthophylls
(D) Heat Shock Proteins (HSPs)

2014

94. Match the cellular stress response component in List I with its primary function in List II during high-temperature stress.
List I: (Component)
P. Heat Shock Factors (HSFs)
Q. Reactive Oxygen Species (ROS)
R. Superoxide Dismutase (SOD)
S. Chaperonins
List II: (Function)
1. Scavenges superoxide radicals
2. Acts as a secondary messenger but causes oxidative damage at high levels
3. Mediates the correct folding of denatured proteins
4. Binds to promoter regions to initiate stress-responsive gene transcription
(A) P-4, Q-2, R-1, S-3
(B) P-2, Q-3, R-4, S-1
(C) P-3, Q-1, R-2, S-4
(D) P-1, Q-4, R-3, S-2

2010

95. The phenomenon where an initial, sub-lethal heat exposure enables a plant to survive a subsequent, otherwise lethal heat shock is defined as:
(A) Vernalization
(B) Acquired thermo-tolerance

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2016

79. What mechanism do guard cells utilize to mediate stomatal closure under elevated intercellular CO_2 concentrations?
(A) Hyperpolarization of the plasma membrane leading to potassium influx
(B) Alterations in ion channel activity (efflux of K^+ and anions) leading to reduced turgor pressure
(C) Synthesis of massive amounts of abscisic acid (ABA) directly from CO_2
(D) Depolymerization of cellulose microfibrils in the cell wall

2019

80. How might the "water-saving effect" of elevated CO_2 influence regional hydrology?
(A) By completely halting the terrestrial hydrological cycle.
(B) By converting soil water into atmospheric methane.
(C) By increasing the evaporative demand of the air.
(D) By increasing deep drainage and potential streamflow.

2009

81. In an ecosystem heavily dominated by deeply rooted C3 woody shrubs, what is the most likely consequence of elevated CO_2 on the soil moisture profile?
(A) Increased moisture retention via reduced transpiration.
(B) Accelerated depletion of moisture in deeper soil layers.
(C) Absolute saturation of all soil layers year-round.
(D) Complete salinization of the topsoil in the region.

2015

82. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A): Elevated CO_2 consistently improves the drought tolerance of C3 crops.
Reason (R): Decreased stomatal conductance under high CO_2 reduces transpirational water loss, conserving soil moisture for prolonged periods.
In light of the above statements, choose the correct answer from the options given below:
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2002

83. What is the typical effect of elevated atmospheric CO_2 on the tissue Carbon-to-Nitrogen ($C{:}N$) ratio in C3 plants?
(A) The $C{:}N$ ratio increases due to enhanced carbon assimilation.
(B) The $C{:}N$ ratio significantly decreases via nitrogen uptake.
(C) The $C{:}N$ ratio remains perfectly homeostatic in the leaf.
(D) The $C{:}N$ ratio fluctuates wildly depending on photoperiod.

2006

84. Which process most directly explains the "dilution effect" observed in the nutritional quality of crops grown under elevated CO_2?
(A) Accelerated accumulation of secondary metabolites.
(B) Direct chemical reaction between CO_2 and soil zinc.
(C) Enhanced leaching of nutrients from the leaf surface.
(D) Excess biomass accumulation that dilutes protein levels.

NODIA

2004

85. The term "sink strength" in plant physiology, particularly concerning elevated CO_2 responses, refers to:
(A) The physical strength of the stem holding the fruit
(B) The capacity of non-photosynthetic organs (roots, tubers, grains) to import and utilize photoassimilates
(C) The efficiency of the leaf in capturing solar radiation
(D) The rate at which the stomata close during darkness

2002

86. How does a severe limitation in plant "sink capacity" affect the photosynthetic response to elevated CO_2?
(A) It causes uninterrupted exponential growth in the stem.
(B) It leads to the complete cessation of dark respiration.
(C) It results in leaf feedback inhibition of photosynthesis.
(D) It forcefully converts the plant into a CAM

2002

71. Arrange the following sequence of physiological events in a C3 leaf exposed to acutely elevated CO_2.

I. Increase in intercellular CO_2 concentration (C_i)
II. Competitive inhibition of Rubisco oxygenase activity
III. Decrease in the rate of photorespiration
IV. Increase in net carbon assimilation rate

Choose the correct sequential order:

(A) II, I, III, IV
(B) I, III, II, IV
(C) I, II, III, IV
(D) III, II, I, IV

2003

72. In comparing C3 and C4 crops, which crop is likely to exhibit the highest percentage increase in biomass due solely to a doubling of atmospheric CO_2?

(A) Triticum aestivum (Wheat)
(B) Zea mays (Maize)
(C) Sorghum bicolor (Sorghum)
(D) Saccharum officinarum (Sugarcane)

2018

73. What is the fundamental reason why the initial stimulation of photosynthesis by elevated CO_2 often diminishes over multiple growing seasons in natural ecosystems?

(A) Rapid evolution of C4 photosynthetic traits in C3 species.
(B) Progressive nitrogen limitation in soil nutrient pools.
(C) Continuous opening of stomata leading to desiccation.
(D) Photochemical smog directly blocking solar radiation.

2023

74. Elevated atmospheric CO_2 typically induces which of the following immediate physiological responses regarding stomata?

(A) Complete stomatal opening to maximize CO_2 influx.
(B) Partial stomatal closure, reducing conductance.
(C) An immediate shedding of leaves to reduce transpiration.
(D) Rapid generation of new stomata on the upper epidermis.

2006

75. How does the interaction of elevated CO_2 and stomatal conductance affect whole-plant transpiration?

(A) It decreases transpiration per leaf area, conserving moisture.
(B) It significantly increases total transpiration per leaf area.
(C) It causes transpiration to reverse, drawing atmospheric water.
(D) It decouples transpiration from the vapor pressure deficit.

2022

76. The calculation of Water Use Efficiency (WUE) at the leaf level is defined as the ratio of:

(A) Total leaf area to total root mass
(B) Atmospheric CO_2 concentration to soil moisture content
(C) Photosynthetic carbon assimilation to stomatal conductance or transpiration
(D) Photorespiration rate to carboxylation rate

2018

77. Which statement accurately describes the expected change in Water Use Efficiency (WUE) for C4 crops under elevated CO_2?

(A) WUE remains unchanged because photosynthesis is stable.
(B) WUE decreases because stomata open wider to cool leaves.
(C) WUE increases because Rubisco speeds up carboxylation.
(D) WUE increases due to reduced stomatal conductance.

2003

78. Consider the following statements regarding elevated CO_2 and plant water relations:

I. Elevated CO_2 generally decreases stomatal density in newly developing leaves over generations.
II. Increased leaf area index (LAI) under elevated CO_2 can offset single-leaf transpiration reductions, leading to similar total canopy water use.
III. Elevated CO_2 increases the susceptibility of plants to minor droughts.
IV. Guard cells primarily rely on aerenchyma signals to sense CO_2 levels.

Which of the above statements is/are correct?

(A) I and III
(B) I and II
(C) II and IV
(D) III and IV

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(C) Isotopic fractionation
(D) Photochemical quenching

2023

96. Which reactive oxygen species (ROS) is highly stable, freely diffuses across membranes, and acts prominently as a signaling molecule during temperature stress?
(A) Hydroxyl radical (•OH)
(B) Singlet oxygen ($1O_2$)
(C) Superoxide anion (O_2•-)
(D) Hydrogen peroxide (H_2O_2)

2019

97. The thermal stability of which specific thylakoid membrane complex is famously vulnerable and acts as a major limiting factor for photosynthesis under heat stress?
(A) Photosystem II (PSII), specifically the oxygen-evolving complex
(B) ATP synthase
(C) Cytochrome b6f
(D) Photosystem I (PSI)

2002

98. How does the unsaturation level of membrane lipids typically respond during acclimation to chronically high temperatures?
(A) It increases to make the membrane much more fluid.
(B) It remains completely unchanged during the process.
(C) It decreases to prevent excessive membrane fluidity.
(D) All lipids are rapidly converted to rigid sterol units.

2010

99. Which biochemical marker is most commonly measured to assess the extent of lipid peroxidation and oxidative membrane damage under heat stress?
(A) Malondialdehyde (MDA) content
(B) Rubisco concentration
(C) Proline content solely
(D) Chlorophyll b to a ratio

2008

100. Consider the following statements regarding heat stress at the cellular level:
I. Heat stress exclusively affects the nucleus, leaving chloroplasts unharmed.
II. Accumulation of misfolded proteins in the endoplasmic reticulum triggers the unfolded protein response.
III. High temperatures generally decrease the rate of dark respiration.
Which of the above statements is/are INCORRECT?
(A) II only
(B) I and II
(C) II and III
(D) I and III

2011

101. During high-temperature stress, osmotic adjustment often occurs to maintain cell turgor. Which of the following is a classic compatible osmolyte accumulated during this process?
(A) Lignin
(B) Proline
(C) Cellulose
(D) Pectin

2014

102. Which reproductive stage in cereal crops is generally considered the most acutely sensitive to brief episodes of high-temperature stress?
(A) Vegetative tillering
(B) Mid-grain filling
(C) Anthesis (flowering and pollination)
(D) Physiological maturity

2017

103. Consider the following statements regarding the impact of high temperature on reproductive biology:
I. High temperatures enhance pollen viability by accelerating tube growth indefinitely.
II. Heat stress can cause indehiscence of the anthers, trapping pollen.
III. Warm night temperatures extend the grain-filling duration, increasing final yield.
IV. Heat stress during microsporogenesis frequently leads to sterile pollen.
V. High temperatures have no effect on female reproductive organ receptivity.
Which of the above statements is/are INCORRECT?
(A) II, IV and V
(B) I, III and V
(C) I, II and IV
(D) III, IV and V

NODIA

2002

104. What is the primary physiological consequence of high night temperatures during the grain-filling period of rice or wheat?
(A) Increased respiration leading to reduced grain weight.
(B) Massive increases in final grain starch

(C) It can lead to a significant increase in N2O emissions.
(D) It reduces the intrinsic water use efficiency of the crop.

2007

55. Match the methane mitigation strategy in List I with its specific target mechanism in List II.
List I: (Mitigation Strategy)
P. Alternate Wetting and Drying (AWD)
Q. 3-Nitrooxypropanol (3-NOP) supplementation
R. Bio-cover application on manure
S. Composting manure instead of liquid storage
List II: (Target Mechanism)
1. Inhibits methyl-coenzyme M reductase in rumens
2. Increases soil redox potential in paddy fields
3. Promotes methanotrophic oxidation at the surface
4. Maintains aerobic conditions during decomposition
(A) P-1, Q-2, R-3, S-4
(B) P-4, Q-1, R-2, S-3
(C) P-2, Q-1, R-3, S-4
(D) P-3, Q-4, R-1, S-2

2011

56. General Circulation Models (GCMs) base their physical simulations primarily on which set of mathematical foundations?
(A) The Navier-Stokes equations for fluid dynamics
(B) The Hardy-Weinberg equations
(C) The Michaelis-Menten kinetic equations
(D) The Arrhenius rate equations exclusively

2004

57. What specific parameter do Representative Concentration Pathways (RCPs) uniquely describe?
(A) The exact trajectory of temperature increase by 2100.
(B) Time-dependent projections of radiative forcing.
(C) The socio-economic narratives of population growth.
(D) The rate of biological carbon sequestration in oceans.

2018

58. Under the RCP 8.5 scenario, what does the numeric value "8.5" signify?
(A) A projected average global temperature rise of 8.5°C by 2100
(B) A radiative forcing of 8.5 W/m² relative to pre-industrial levels by the year 2100
(C) An atmospheric CO_2 concentration of 8.5 ppm
(D) A sea-level rise of 8.5 meters

2023

59. Which of the following is a fundamental limitation of utilizing coarse-resolution General Circulation Models for agricultural planning?
(A) They lack the ability to capture localized climate features.
(B) They are entirely incapable of simulating ocean currents.
(C) They cannot be integrated with any emissions scenarios.
(D) They assume the atmosphere has zero greenhouse gases.

2010

60. Select the correct sequence of steps involved in standard regional climate prediction downscaling.
I. Applying Regional Climate Models (RCMs) or statistical downscaling
II. Selecting appropriate RCP scenarios
III. Inputting regional climate data into agricultural impact models
IV. Running the General Circulation Model (GCM)
Which of the options represents the correct sequential order?
(A) I, II, IV, III
(B) IV, I, III, II
(C) III, I, IV, II
(D) II, IV, I, III

2007

61. Identify the INCORRECT statement regarding Representative Concentration Pathways (RCPs).
(A) RCP 2.6 represents a stringent mitigation scenario designed to keep global warming below 2°C.
(B) RCP 8.5 represents a baseline scenario with no significant climate mitigation policies.
(C) They span a wide range of possible future radiative forcing values.
(D) They exclusively prescribe fossil fuel emissions and ignore land-use changes.

2012

62. The process of deriving higher-resolution local climate data from lower-resolution GCM outputs is termed:
(A) Upscaling
(B) Isotopic fractionation

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(D) Delayed maturity extending into the winter frost season.

2018

114. How does elevated CO_2 generally interact with high-temperature-induced stomatal opening (for leaf cooling)?
(A) Elevated CO_2 reinforces stomatal opening for cooling.
(B) The two factors completely cancel each other out.
(C) CO_2 triggers closure, exacerbating leaf heat stress.
(D) Elevated CO_2 physically destroys the guard cells.

2021

115. Identify the primary factor that limits net productivity when a crop is subjected to both highly elevated CO_2 and severe terminal heat stress.
(A) Shortened grain-filling period and heat-induced spikelet sterility
(B) Accelerated Rubisco synthesis
(C) Extreme suppression of dark respiration
(D) Excessive retention of photosynthates in the root system

2007

116. Consider the following statements regarding combined CO_2 and temperature effects:
I. Increased photorespiration at high temperatures is further enhanced by elevated CO_2.
II. The fertilization effect of elevated CO_2 is generally more pronounced at warmer temperatures (up to the thermal optimum).
III. Interactive effects on crop yield are strictly additive and never antagonistic.
IV. Elevated CO_2 generally increases the $Q_{\{10\}}$ value of photorespiration.
Which of the above statements is/are INCORRECT?
(A) I, III and IV
(B) II, III and IV
(C) I, II and III
(D) I and IV

2015

117. What is the overall effect on the ecosystem carbon balance if warming-induced increases in soil respiration outpace CO_2-induced increases in net primary productivity (NPP)?
(A) The ecosystem becomes a stronger carbon sink.
(B) The ecosystem shifts from being a carbon sink to a carbon source.
(C) The ecosystem's carbon cycle immediately ceases.
(D) The atmospheric CO_2 concentration abruptly plummets.

2025

118. Which statement best describes the coupled impact of elevated CO_2 and elevated temperature on whole-plant water use?
(A) Both force absolute stomatal closure, stopping loss.
(B) Water use strictly decreases regardless of the deficit.
(C) CO_2 reduces loss but higher temperatures increase demand.
(D) High temperatures freeze the guard cells open permanently.

2003

119. In terms of crop growth modeling, when temperature exceeds the specific upper threshold for a cultivar while CO_2 is elevated, what occurs?
(A) Elevated CO_2 protects the plant from all damage.
(B) The plant switches to a purely structural growth phase.
(C) Elevated CO_2 is immediately metabolized into coolant.
(D) Yield plummets as reproductive damage nullifies benefits.

2006

120. Chlorofluorocarbons (CFCs) are exceptionally stable in the troposphere. In which atmospheric layer do they finally undergo photolytic decomposition?
(A) Stratosphere
(B) Troposphere
(C) Mesosphere
(D) Thermosphere

2005

121. The catalytic destruction of stratospheric ozone by CFCs is primarily mediated by the release of which specific free radical upon exposure to intense UV radiation?
(A) Hydroxyl radical (•OH)
(B) Chlorine atom (Cl•)
(C) Fluorine atom (F•)
(D) Carbon-centered radical (C•)

2012

122. Which sequence correctly represents the primary catalytic cycle of ozone depletion by chlorine?

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(A) $Cl + O_3 \rightarrow ClO + O_2$; $ClO + O \rightarrow Cl + O_2$
(B) $Cl + O_2 \rightarrow ClO_2$; $ClO_2 + O_3 \rightarrow Cl + 2O_2$
(C) $Cl + O \rightarrow ClO$; $ClO + O_3 \rightarrow Cl + 2O_2$
(D) $Cl_2 + O_3 \rightarrow Cl2O + O_2$; $Cl_2O + O \rightarrow Cl_2 + O_2$

2004

123. What unique meteorological feature is strictly necessary for the massive, rapid formation of the "Ozone Hole" over Antarctica during the austral spring?
(A) The presence of Polar Stratospheric Clouds (PSCs) and the isolated polar vortex
(B) Intense tropospheric thunderstorms
(C) Persistent equatorial trade winds
(D) Massive oceanic outgassing of methane

2010

124. Why are Polar Stratospheric Clouds (PSCs) critical to the severe depletion of Antarctic ozone?
(A) They physically block UV light from entering.
(B) They absorb ozone into ice crystals permanently.
(C) They convert inert reservoirs into active chlorine.
(D) They release natural halocarbons into the air.

2012

125. The internationally ratified treaty responsible for the successful phase-out of CFCs and other ozone-depleting substances is known as the:
(A) Kyoto Protocol
(B) Paris Agreement
(C) Basel Convention
(D) Montreal Protocol

2022

126. Which class of compounds was introduced as a transitional replacement for CFCs because they have much shorter tropospheric lifetimes, though they are still potent greenhouse gases?
(A) Sulfur hexafluorides (SF6)
(B) Perfluorocarbons (PFCs)
(C) Hydrochlorofluorocarbons (HCFCs)
(D) Brominated flame retardants

2017

127. Identify the INCORRECT statement regarding the atmospheric chemistry of ozone.
(A) Stratospheric ozone is naturally created through the Chapman cycle.
(B) Nitrogen oxides (NOx) cannot participate in catalytic ozone destruction cycles.
(C) A single chlorine atom can destroy up to 100,000 ozone molecules before being neutralized.
(D) The maximum concentration of the ozone layer is located roughly 20-30 km above the Earth's surface.

2008

128. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A): The Antarctic ozone hole occurs primarily during the Southern Hemisphere's winter (July-August).
Reason (R): The return of sunlight in the austral spring (September-October) is strictly required to photolyze Cl2 into the destructive Cl• radicals.
In light of the above statements, choose the correct answer from the options given below:
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

NODIA

2023

129. Based on wavelength classification, which type of ultraviolet radiation is the most energetic and entirely absorbed by the atmosphere before reaching Earth's surface?
(A) UV-C (100–280 nm)
(B) UV-B (280–315 nm)
(C) UV-A (315–400 nm)
(D) Photosynthetically Active Radiation (400–700 nm)

2010

130. What is the most prominent, direct photobiological damage inflicted upon plant DNA by elevated UV-B radiation?
(A) Deletion of entire chromosomes
(B) Immediate conversion of DNA into RNA
(C) Formation of cyclobutane pyrimidine dimers (CPDs) and 6-4 photoproducts
(D) Massive double-strand DNA breakage primarily in the centromere

2021

131. Which of the following wavelengths accurately defines the UV-B spectrum?
(A) 10–100 nm
(B) 280–315 nm
(C) 315–400 nm
(D) 400–700 nm

2001

132. How does elevated UV-B radiation generally affect the morphological development of plants?
(A) It drastically increases internode elongation globally.
(B) It induces continuous, non-stop seasonal flowering.
(C) It causes the root system to grow above the soil.
(D) It causes stunting and increased leaf thickness.

2024

133. Which cellular macromolecule strongly absorbs UV-B radiation, leading directly to structural deformation?
(A) Cellulose
(B) DNA and aromatic amino acids in proteins
(C) Sucrose
(D) Water

2011

134. Which specific photoreceptor mediates the plant's physiological and morphological responses (acclimation) specifically to UV-B light?
(A) Phytochrome A
(B) Phototropin
(C) UVR8
(D) Cryptochrome

2016

135. What is the physiological consequence of UV-B-induced destruction of the D1 protein in the chloroplast?
(A) Rapid enhancement of cyclic electron flow.
(B) Immediate opening of stomatal pores.
(C) Massive accumulation of bundle sheath starch.
(D) Inhibition of PSII electron transport.

2019

136. Identify the exception. All of the following are recognized consequences of elevated UV-B exposure in crop plants, EXCEPT:
(A) Extreme enhancement of the carbon fertilization effect
(B) Increased epidermal accumulation of secondary metabolites
(C) Reduction in total biomass and yield
(D) Increased incidence of cyclobutane pyrimidine dimers

2010

137. Select the correct sequence of UV-B signal transduction mediated by the specific photoreceptor.
I. Monomerization of the photoreceptor complex
II. Interaction with COP1 (Constitutively Photomorphogenic 1)
III. Absorption of UV-B by UVR8 homodimers
IV. Activation of HY5 transcription factor
(A) III, I, II, IV
(B) I, III, IV, II
(C) III, II, I, IV
(D) IV, I, II, III

2012

138. The molecular mechanism of "photoreactivation" repair in plants strictly requires which specific enzyme and environmental cue?
(A) DNA ligase and complete darkness
(B) Photolyase and blue/UV-A light (350-450 nm)
(C) RNA polymerase and red light
(D) Endonuclease and high temperature

2021

139. How does Nucleotide Excision Repair (NER) differ from photoreactivation in repairing UV-B damaged DNA?
(A) NER is a light-independent dark repair mechanism.
(B) NER can only occur during active photosynthesis.
(C) NER exclusively repairs double-strand breaks.
(D) NER requires photolyase to reverse the dimer.

2006

140. Which specific lesion is primarily targeted by the enzyme photolyase during DNA repair?
(A) Alkylated guanine bases
(B) Missing base sites (AP sites)
(C) Cyclobutane pyrimidine dimers (CPDs)
(D) Thymine-adenine mismatched base pairs

2022

141. Identify the INCORRECT statement regarding plant DNA repair mechanisms.
(A) Photoreactivation is generally more energetically efficient than nucleotide excision repair.
(B) Plants continuously exposed to sunlight rely heavily on photolyase to maintain genome integrity.
(C) Dark repair pathways (NER) are entirely absent in higher plants.
(D) UV-induced damage often outpaces repair capacity during acute stress events.

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II. They require large volumes of liquid CO_2, making them highly expensive to run.
III. They struggle to maintain target CO_2 levels perfectly under highly turbulent or stagnant wind conditions.
IV. They are strictly limited to studying single, isolated plants rather than entire canopies.

Which of the above statements is/are INCORRECT?
(A) I and II
(B) II and III
(C) I and IV
(D) III and IV

2012

179. A classic discovery from early FACE experiments on crops like wheat and rice was that:
(A) The actual yield increase under open-field elevated CO_2 was often significantly lower than previously predicted by enclosure (OTC) studies.
(B) Elevated CO_2 turned all C3 plants strictly into C4 plants.
(C) Photosynthesis completely ceased under elevated CO_2.
(D) Insect herbivory was completely eradicated by elevated CO_2.

2008

180. How is the release of CO_2 specifically controlled in a standard FACE ring?
(A) It is released at a constant, unvarying daily rate.
(B) It is manually adjusted based on weather forecasts.
(C) It is triggered only when it begins to rain at night.
(D) It is controlled via real-time wind and sensor data.

2022

181. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A): FACE experiments are highly suited for studying large-scale ecosystem dynamics and biogeochemical cycling under elevated CO_2.
Reason (R): They allow entire crop canopies, deeply rooted trees, and undisturbed soil food webs to experience elevated CO_2 without structural confinement.
In light of the above statements, choose the correct answer from the options given below:
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

NODIA

2005

182. Which limitation is most commonly cited when interpreting results from Free-Air CO_2 Enrichment (FACE) arrays?
(A) The inability to grow any plants inside the ring.
(B) The creation of intense artificial chamber shading.
(C) Step-increase artifacts from sudden gas exposure.
(D) The rapid depletion of soil oxygen to lethal levels.

2012

183. In large-scale forest FACE experiments, what persistent issue often limits the long-term carbon sequestration potential initially stimulated by elevated CO_2?
(A) Immediate shedding of all bark
(B) Reversal of gravity affecting sap flow
(C) Excessive overproduction of Rubisco
(D) Progressive Nitrogen Limitation (PNL) in the soil

2017

184. Through which primary anatomical pathway does atmospheric Sulfur Dioxide (SO_2) enter the interior of a plant leaf?
(A) Through open stomata during gas exchange
(B) Directly through the intact waxy cuticle
(C) Via the root system after dissolving in soil water
(D) Exclusively through hydathodes during guttation

2015

185. What is the immediate biochemical consequence once SO_2 dissolves in the aqueous film lining the mesophyll cell walls?
(A) It rapidly forms heavily insoluble calcium crystals.
(B) It forms toxic sulfite ions and generates ROS.
(C) It immediately binds to chlorophyll, turning leaves.
(D) It is instantly assimilated into methionine amino acids.

scavenging
(B) Proline : Osmotic adjustment
(C) Flavonols : Protection of mesophyll cells from UV-B penetration
(D) Lignin : Exclusively for primary DNA repair

2002

152. How does the synthesis of UV-absorbing compounds provide a competitive advantage to alpine plants?
(A) It protects their photosynthetic apparatus and DNA from the intense UV radiation characteristic of high altitudes.
(B) It allows them to photosynthesize completely in the dark.
(C) It generates significant metabolic heat, preventing freezing.
(D) It prevents them from being detected by visual predators.

2019

153. What is the secondary benefit of increased epidermal flavonoid accumulation during severe environmental stress, apart from UV-screening?
(A) Serving as primary nitrogen storage sinks
(B) Acting as potent antioxidants to scavenge reactive oxygen species (ROS)
(C) Acting as structural components replacing cellulose in the cell wall
(D) Enhancing the uptake of atmospheric nitrogen gas

2023

154. Consider the following statements regarding UV-screening compounds:
I. They absorb UV-B radiation while remaining largely transparent to Photosynthetically Active Radiation (PAR).
II. Chalcone synthase is a key enzyme specifically directing carbon into the flavonoid pathway.
III. They are transported into the chloroplast to directly shield the DNA.
IV. Their synthesis is strongly down-regulated by the UVR8 photoreceptor.
V. They can attenuate up to 90% of incident UV-B before it reaches the mesophyll.
Which of the above statements is/are correct?
(A) I, II and IV
(B) I, II and V
(C) II, III and V
(D) I, III and IV

2019

155. Which structural property of flavonoids allows them to act as effective UV filters and antioxidants?
(A) The presence of a highly conjugated system of alternating double bonds and aromatic rings
(B) A long, saturated aliphatic hydrocarbon chain
(C) The presence of multiple reactive chlorine atoms
(D) A strict linear protein structure

2019

156. In agricultural systems, why might an overly aggressive breeding program aimed at strictly reducing "bitter" phenolic compounds in foliage inadvertently decrease crop resilience?
(A) It increases the plant's resistance to cold stress.
(B) It forces the plant to rely entirely on C4 pathways.
(C) It strips the plant of its natural UV-B defenses.
(D) It causes the crop to prematurely drop all fruits.

2003

157. What is the primary function of carotenoids in the context of high-light or heat stress?
(A) To synthesize ATP directly from heat
(B) To act as structural pillars within the vacuole
(C) To fix excess CO_2 in the bundle sheath
(D) To dissipate excess excitation energy safely as heat via non-photochemical quenching (NPQ)

2001

158. The xanthophyll cycle strictly involves the enzymatic, light-dependent conversion between which specific molecules?
(A) Lutein, Zeaxanthin, and beta-carotene
(B) Chlorophyll a, Chlorophyll b, and Pheophytin
(C) Violaxanthin, Antheraxanthin, and Zeaxanthin
(D) ATP, ADP, and AMP

2019

159. Under severe excess light and climatic stress, which xanthophyll cycle pigment accumulates heavily to mediate thermal dissipation of energy?
(A) Violaxanthin
(B) Zeaxanthin
(C) Neoxanthin
(D) Lutein epoxide

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between the veins
(B) Massive hyper-elongation of the petiole
(C) Interveinal chlorosis starting strictly from the lower veins
(D) Complete rotting of the root system

2002

196. Match the specific air pollutant in List I with its defining characteristic or effect in List II.
List I: (Air Pollutant)
P. Tropospheric Ozone (O_3)
Q. Peroxyacetyl Nitrate (PAN)
R. Sulfur Dioxide (SO_2)
S. Acid Rain ($pH < 5.0$)
List II: (Effect)
1. Causes characteristic "glazing" or "bronzing" on the lower leaf surface
2. Induces aluminum toxicity in forest soils
3. Primary secondary pollutant causing upper-surface leaf flecking
4. Primary pollutant causing interveinal bleached lesions
(A) P-1, Q-3, R-2, S-4
(B) P-3, Q-4, R-1, S-2
(C) P-4, Q-1, R-3, S-2
(D) P-3, Q-1, R-4, S-2

2005

197. Peroxyacetyl Nitrate (PAN) is highly toxic to plants because it:
(A) Immediately freezes cellular water upon entry.
(B) Collapses mesophyll cells, causing leaf bronzing.
(C) Replaces all nitrogen in the plant's DNA structure.
(D) Acts as an impenetrable barrier over the stomata.

2023

198. Which plant defense hormone signaling pathway is predominantly rapidly activated in response to ozone-induced oxidative stress?
(A) Gibberellic acid pathway
(B) Strigolactone pathway
(C) Salicylic acid and Ethylene/Jasmonic acid pathways
(D) Cytokinin pathway

2022

199. Chronic, low-level exposure to tropospheric ozone primarily reduces crop yield through which specific mechanism?
(A) Over-stimulation of the reproductive organs globally.
(B) Immediate destruction of all root nodules in soil.
(C) Complete inhibition of seed germination in crops.
(D) Accelerated leaf senescence and reduced assimilation.

2011

200. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A): Elevated atmospheric CO_2 can often mitigate the phytotoxic damage caused by high tropospheric ozone.
Reason (R): Elevated CO_2 generally induces stomatal closure, significantly restricting the physical uptake of ozone into the leaf interior.
In light of the above statements, choose the correct answer from the options given below:
(A) Both A and R are true but R is not the correct explanation of A.
(B) A is true but R is false.
(C) A is false but R is true.
(D) Both A and R are true and R is the correct explanation of A.

NODIA

2009

201. Which metric evaluates the amount of dissolved oxygen required by aerobic microorganisms to break down organic material in a water body?
(A) Chemical Oxygen Demand (COD)
(B) Biological Oxygen Demand (BOD)
(C) Dissolved Organic Carbon (DOC)
(D) Eutrophication Index (EI)

2021

202. How does Chemical Oxygen Demand (COD) fundamentally differ from Biological Oxygen Demand (BOD)?
(A) COD only measures the oxygen required for inorganic matter.
(B) COD uses chemical oxidants to measure total oxidizable matter.
(C) COD is strictly measured over a period of 5 months in total.
(D) COD utilizes live fish to measure toxicity levels in samples.

2014

203. The primary ecological consequence of discharging raw domestic effluents with extremely high BOD into a slow-moving river is:
(A) Severe depletion of Dissolved Oxygen (DO), leading to hypoxia and massive fish kills
(B) Rapid hyper-oxygenation of the water

(B) They perfectly replicate natural field microclimates without any artifacts.
(C) The open top allows for natural precipitation and insect access, though often slightly altered.
(D) Air containing the target gas is typically continuously pumped into the chamber through lower distribution manifolds.

2011

170. Consider the following statements regarding experimental climate structures:
I. OTCs suffer from a "chamber effect" that can confound plant responses.
II. TGTs are exceptionally useful for studying temperature responses precisely because they establish continuous thermal gradients.
III. OTCs completely eliminate the boundary layer resistance of leaves.
Which of the above statements is/are correct?
(A) I and III
(B) I and II
(C) II and III
(D) I only

2018

171. Why might the estimation of evapotranspiration from an OTC experiment not perfectly extrapolate to open field conditions?
(A) The walls reduce wind and alter the boundary layer.
(B) Because plants in OTCs stop transpiring completely.
(C) Because OTCs strictly utilize distilled water only.
(D) Because the walls absorb all incoming solar radiation.

2008

172. When calculating crop yield responses to elevated CO_2 using OTCs, researchers typically must compare the elevated chambers to which critical control?
(A) Unchambered open field plots only
(B) Chambers placed completely in the dark
(C) Chambers with ambient CO_2 blown in as a control
(D) Chambers filled exclusively with pure nitrogen gas

2013

173. What is the primary advantage of using a Temperature Gradient Tunnel (TGT) over a series of strictly isolated, single-temperature growth chambers?
(A) TGTs ensure the plants never experience natural light.
(B) TGTs are structurally immune to hurricane-force winds.
(C) TGTs are small enough to fit inside a refrigerator.
(D) TGTs provide a continuous temperature response curve.

2018

174. Which microclimatic variable is most notoriously difficult to control and keep uniform within an Open Top Chamber, particularly on windy days?
(A) Total soil depth
(B) Incident photoperiod
(C) Target gas concentration (e.g., CO_2) due to incursion of ambient air from the open top
(D) The absolute gravitational pull

2015

175. What does the acronym FACE stand for in the context of climate change research?
(A) Forced Aeration Climate Environment
(B) Free-Air CO_2 Enrichment
(C) Field Agricultural Carbon Extraction
(D) Fluctuating Atmospheric Carbon Evaluator

2007

176. What is the fundamental engineering principle behind a FACE system?
(A) Sealing a massive tract of land under a glass dome.
(B) Releasing CO_2 from vent pipes using natural wind.
(C) Injecting massive quantities of dry ice into subsoil.
(D) Irradiating an open field with intense microwaves.

2024

177. The primary scientific advantage of FACE technology over Open Top Chambers (OTCs) is:
(A) Enrichment without altering the natural microclimate.
(B) FACE systems are significantly cheaper to maintain.
(C) FACE systems completely eliminate natural insect pests.
(D) FACE systems guarantee a completely static CO_2 level.

2005

178. Consider the following statements regarding FACE systems:
I. They inherently suffer from massive "chamber effects."

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2021

160. What biochemical condition specifically triggers the enzyme violaxanthin de-epoxidase (VDE) to convert violaxanthin to zeaxanthin?
(A) A highly alkaline pH in the stroma
(B) A strictly neutral pH across the chloroplast
(C) The accumulation of massively high levels of sucrose
(D) A heavily acidified thylakoid lumen (low pH) resulting from excessive electron transport

2004

161. In addition to photoprotection, what crucial structural role do carotenoids play in the thylakoid membrane?
(A) They stabilize lipid membranes and Light-Harvesting Complexes against oxidative destruction.
(B) They serve as the primary channel for water splitting.
(C) They bind exclusively to DNA to prevent mutation.
(D) They act as rigid pores for CO_2 entry.

2007

162. Determine the correct sequence of states in the xanthophyll cycle starting from the dark-adapted state to the severe high-light stress state.
I. Zeaxanthin
II. Violaxanthin
III. Antheraxanthin
(A) I, II, III
(B) II, III, I
(C) III, I, II
(D) II, I, III

2002

163. How does zeaxanthin physically facilitate non-photochemical quenching (NPQ)?
(A) By dissipating chlorophyll excitation energy as heat.
(B) By reflecting incident photons back into the atmosphere.
(C) By detaching the light-harvesting complex from PSII.
(D) By converting excess light energy into radio waves.

2014

164. What defines "photoinhibition" in the context of extreme climate stress?
(A) The light-induced acceleration of the Calvin cycle.
(B) Beneficial suppression of stomata during high wind.
(C) The inability of roots to absorb water in light.
(D) A sustained decrease in the quantum yield of PSII.

2019

165. Why is the recovery phase of the xanthophyll cycle (conversion of zeaxanthin back to violaxanthin) slower than the forward stress response?
(A) It requires the resynthesis of the entire chloroplast.
(B) It depends on the stroma-based zeaxanthin epoxidase.
(C) It requires absolute zero temperatures to proceed.
(D) The plant must first absorb UV-B light to reverse it.

NODIA

2025

166. Open Top Chambers (OTCs) are classical field structures used primarily to study the effects of:
(A) Deep ocean pressure on marine algae
(B) Soil compaction on root architecture
(C) Elevated atmospheric trace gases (like CO_2 or O3) on crops under semi-natural conditions
(D) Complete zero-gravity on seedling geotropism

2019

167. Which of the following is considered the most significant limitation or "chamber effect" associated with Open Top Chambers (OTCs)?
(A) They are entirely enclosed, blocking all rainfall.
(B) They are incapable of maintaining any gas levels.
(C) They require the use of artificial soil exclusively.
(D) They artificially alter the internal microclimate.

2011

168. How does a Temperature Gradient Tunnel (TGT) function in climate change research?
(A) Using a forced airflow that is progressively heated.
(B) By physically dragging plants through climate zones.
(C) By freezing the soil at one end and boiling the other.
(D) By exposing plants to gradients of heavy metal toxins.

2014

169. Identify the INCORRECT statement regarding Open Top Chambers (OTCs).
(A) They are generally less expensive to construct and operate than FACE systems.

2025

186. Foliar necrosis induced by acute SO_2 exposure typically presents visually as:
(A) A uniform deep reddening of the entire plant stem
(B) Interveinal, distinctly bleached (chlorotic or necrotic) lesions on mature leaves
(C) Extreme swelling and blistering of the leaf epidermis
(D) Continuous bleeding of sap from the leaf margins

2025

187. Acid rain is primarily caused by the atmospheric oxidation and hydrolysis of which two specific primary pollutants?
(A) Sulfur dioxide (SO_2) and Nitrogen oxides (NOx)
(B) Ozone and Peroxyacetyl Nitrate (PAN)
(C) Carbon dioxide and Methane
(D) Chlorofluorocarbons and Halons

2025

188. What is the major indirect consequence of chronic acid rain on forest ecosystems?
(A) Increased availability of soil phosphorus
(B) Massive overpopulation of earthworms
(C) Heavy leaching of basic cations (Ca^{2+}, Mg^{2+}) and mobilization of toxic aluminum (Al^{3+}) in the soil
(D) Complete petrification of tree trunks

2012

189. How do plants attempt to detoxify sublethal levels of internalized sulfite (SO_3^{2-})?
(A) By directly pumping it out of the stomata as gas.
(B) By converting it into pure elemental sulfur crystals.
(C) By binding it irreversibly to the DNA double helix.
(D) By oxidizing it to less toxic sulfate via enzymes.

2007

190. Consider the following statements regarding NOx phytotoxicity:
I. NO_2 is significantly more phytotoxic than NO.
II. NOx uptake can inadvertently serve as a nitrogen source at extremely low concentrations.
III. High acute doses of NO_2 primarily cause immediate root necrosis.
Which of the above statements is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I, II and III

2008

191. Exposure to moderate levels of SO_2 often causes a paradoxical response in stomatal behavior. What is this response?
(A) Stomata become permanently sealed shut by sulfate crystals.
(B) Stomata may remain abnormally open, leading to severe desiccation under drought conditions.
(C) Stomata completely disintegrate.
(D) Stomata migrate to the upper epidermis.

NODIA

2012

192. Which cellular organelle is the primary site of damage when heavy bisulfite accumulation severely disrupts electron transport and photophosphorylation?
(A) The Golgi apparatus
(B) The smooth endoplasmic reticulum
(C) The nucleolus
(D) The chloroplast

2014

193. Photochemical smog is fundamentally characterized by the presence of secondary pollutants generated by the action of sunlight on:
(A) Nitrogen oxides (NOx) and Volatile Organic Compounds (VOCs)
(B) Particulate matter and heavy metals
(C) Carbon dioxide and water vapor
(D) Sulfur dioxide and atmospheric ammonia

2024

194. Tropospheric ozone (O_3), a potent phytotoxic secondary pollutant, causes damage primarily by:
(A) Blocking stomatal pores physically as particulate.
(B) Substituting for CO_2 in the Calvin-Benson cycle.
(C) Generating ROS that degrade cellular membranes.
(D) Directly dissolving the waxy cuticle upon contact.

2004

195. Which visible symptom is widely considered the classic diagnostic indicator of acute ozone injury in broad-leaved crops?
(A) Upper-surface "flecking" or "stippling" (small pigmented or necrotic spots) usually

2017

142. The "dark repair" pathway for UV-B induced DNA damage utilizes a suite of enzymes. Which of the following is responsible for synthesizing the new DNA strand after the lesion is excised?
(A) DNA helicase
(B) DNA photolyase
(C) DNA polymerase
(D) RNA primase

2009

143. Which of the following best demonstrates the concept of UV-B acclimation in crop plants?
(A) Immediate cellular apoptosis of all epidermal tissues.
(B) Increased synthesis of protective screening compounds.
(C) Complete loss of photolyase activity in the leaf.
(D) Shedding of all true leaves within 24 hours.

2016

144. What happens when a mutant plant lacking the functional UVR8 gene is exposed to ambient UV-B levels?
(A) It completely repairs all DNA damage via dark repair.
(B) It turns its leaves away from the sun via tropism.
(C) It rapidly synthesizes massive amounts of anthocyanins.
(D) It fails to upregulate UV-absorbing flavonoids.

2005

145. Match the UV stress response or repair mechanism in List I with its defining characteristic in List II.
List I: (Mechanism)
P. UVR8 activation
Q. Photoreactivation
R. Nucleotide Excision Repair
S. Flavonoid synthesis
List II: (Characteristic)
1. Accumulation in the vacuole of epidermal cells
2. Excision of a roughly 30-base oligonucleotide sequence
3. Tryptophan-mediated UV-B absorption causing monomerization
4. Direct electron transfer via FADH- to a pyrimidine dimer
(A) P-3, Q-4, R-2, S-1
(B) P-4, Q-3, R-1, S-2
(C) P-1, Q-2, R-3, S-4
(D) P-2, Q-1, R-4, S-3

2002

146. Which specific class of phenolic compounds plays the most crucial role in absorbing potentially damaging UV-B radiation in the plant epidermis?
(A) Flavonoids (e.g., flavonols, anthocyanins) and sinapate esters
(B) Lignins
(C) Alkaloids
(D) Terpenoids

2022

147. Which of the following phenolic acids, commonly found in the cell walls of grasses, acts as a primary UV-B screening compound?
(A) Ferulic acid
(B) Abscisic acid
(C) Gibberellic acid
(D) Indole-3-acetic acid

2024

148. In which specific subcellular compartment of the epidermal cells do UV-screening flavonoids primarily accumulate?
(A) The mitochondrial matrix
(B) The thylakoid lumen
(C) The nucleolus
(D) The central vacuole

2023

149. Why are sinapate esters (like sinapoyl malate) particularly critical for UV protection in species like Arabidopsis thaliana?
(A) They repair DNA lesions directly via electron transfer.
(B) They exhibit strong absorption squarely in the UV-B range.
(C) They actively reflect visible light to prevent leaf heating.
(D) They bind heavy metals to prevent oxidative stress.

2002

150. Which enzyme acts as the critical initial rate-limiting step in the biosynthesis of all phenylpropanoids, including UV-absorbing flavonoids?
(A) Rubisco
(B) Chalcone synthase (CHS)
(C) Phenylalanine ammonia-lyase (PAL)
(D) Superoxide dismutase (SOD)

2003

151. Identify the INCORRECT pair regarding secondary metabolites and their primary environmental function.
(A) Anthocyanins : UV-screening and ROS

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(C) Immediate freezing of the water column
(D) Spontaneous generation of highly complex reef ecosystems

2022

204. Which two macronutrients are primarily responsible for driving the process of cultural eutrophication in freshwater ecosystems?
(A) Carbon and Oxygen
(B) Iron and Zinc
(C) Nitrogen and Phosphorus
(D) Calcium and Magnesium

2017

205. The explosive growth of cyanobacteria or algae (algal blooms) during eutrophication creates "dead zones" primarily because:
(A) They physically strangle aquatic life with long vines.
(B) They secrete concentrated hydrochloric acid into pools.
(C) They convert all local water into pure nitrogen gas.
(D) Dying biomass decomposition consumes dissolved oxygen.

2024

206. Which is a characteristic feature of a highly eutrophic lake compared to an oligotrophic lake?
(A) Exceptionally high water clarity and light penetration
(B) Extremely deep light compensation point
(C) High turbidity, shallow photic zone, and frequent anoxic hypolimnion
(D) High benthic biodiversity dominated by oxygen-sensitive species

2012

207. What critical role do aquatic macrophytes play in mitigating the effects of mild eutrophication?
(A) They synthesize massive amounts of BOD.
(B) They act as nutrient sinks, directly outcompeting phytoplankton for dissolved nitrogen and phosphorus.
(C) They actively hunt and consume cyanobacteria.
(D) They rapidly boil the water to destroy toxins.

2009

208. Which specific standard metric indicates a healthy, unpolluted aquatic ecosystem capable of supporting diverse aquatic fauna?
(A) A BOD exceeding 500 mg/L
(B) A COD to BOD ratio of exactly 1:100
(C) Absolute zero levels of Dissolved Oxygen
(D) High levels of Dissolved Oxygen (DO), typically above 5-6 mg/L

2009

209. Industrial effluents from electroplating or leather tanning frequently introduce which class of potent phytotoxic pollutants into surrounding agricultural soils?
(A) Heavy metals and metalloids (e.g., Chromium, Cadmium)
(B) Chlorofluorocarbons
(C) Radioactive isotopes
(D) Biogenic Volatile Organic Compounds

2010

210. How do heavy metals like Cadmium (Cd) fundamentally disrupt physiological functions within plant cells?
(A) Safely substituting for magnesium in the chlorophyll.
(B) Directly increasing the thickness of the waxy cuticle.
(C) Binding to sulfhydryl groups and inhibiting enzymes.
(D) Continuously generating massive amounts of pure ATP.

2004

211. The process by which the concentration of heavy metals exponentially increases at successively higher trophic levels within an aquatic food web is defined as:
(A) Biomagnification
(B) Bioremediation
(C) Isotopic fractionation
(D) Eutrophication

2012

212. Which family of small, cysteine-rich peptides is actively synthesized by plants to safely chelate and sequester toxic heavy metals in the vacuole?
(A) Phytoalexins
(B) Heat shock proteins
(C) Chaperonins
(D) Phytochelatins

2016

213. Identify the INCORRECT statement regarding the behavior of heavy metals in ecosystems.
(A) They tend to accumulate in the benthic sediments of aquatic ecosystems.
(B) They are completely biodegradable by natural soil bacteria within a few weeks.
(C) Acidic soil conditions generally increase the bioavailability and uptake of toxic heavy metals by plants.

NODIA

(D) Lead (Pb) primarily accumulates in the root systems of most plants with limited translocation to the shoot.

2016

214. Which specific metalloid is notorious for its massive accumulation in rice grains grown in flooded, contaminated soils due to its chemical similarity to silicic acid?
(A) Mercury (Hg)
(B) Lead (Pb)
(C) Arsenic (As)
(D) Uranium (U)

2019

215. What is the primary physiological reason that flooding exacerbates arsenic uptake in paddy rice compared to aerobically grown wheat?
(A) Flooding specifically melts the root epidermis layer.
(B) Flooding forces plants to only absorb heavy metals.
(C) Water acts to magnify UV light which activates arsenic.
(D) Reduced arsenite is readily taken up via aquaporins.

2011

216. In the context of heavy metal toxicity, the phenomenon of "chlorosis" is frequently observed primarily because metals like Cadmium and Zinc:
(A) Competitively inhibit the uptake of essential Iron.
(B) Directly dye the leaf tissues yellow in the field.
(C) Induce an immediate shedding of all true leaves.
(D) Physically shatter the chloroplast membrane units.

2016

217. Agronomic adaptation to terminal heat stress in wheat heavily relies on breeding for which specific trait?
(A) Indeterminate growth habit yielding zero grain harvest.
(B) Stay-green trait extending grain-filling photosynthesis.
(C) Complete loss of all functional stomatal pores in leaf.
(D) Massive hyper-elongation of the root system exclusively.

2002

218. Shifting crop phenology as a climate adaptation strategy primarily involves:
(A) Forcing a summer crop to strictly grow under heavy winter snowpack
(B) Altering the sowing date (e.g., early planting) to ensure critical reproductive stages avoid peak mid-summer heat or terminal drought
(C) Completely halting the plant's life cycle in the vegetative stage
(D) Modifying the plant to require 24 hours of continuous daylight

2004

219. Which microclimate modification technique is highly effective at buffering orchard crops against sudden unseasonal spring frosts?
(A) Utilizing overhead sprinkler irrigation to release latent heat of fusion as the water freezes on the buds
(B) Deploying giant mirrors to reflect the moon's light
(C) Pumping massive amounts of sulfur dioxide into the canopy
(D) Stripping all the bark off the trees

2021

220. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A): Developing crop varieties with a deeper, more robust root architecture is a critical genetic strategy for drought resilience.
Reason (R): Deeper roots can access subsoil moisture reserves that remain stable long after the topsoil has severely desiccated.
In light of the above statements, choose the correct answer from the options given below:
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2004

221. Conservation agriculture practices, such as zero-tillage with heavy crop residue retention, modify the soil microclimate primarily by:
(A) Massively increasing the diurnal temperature amplitude.
(B) Preventing absolutely all gas exchange with the air.
(C) Increasing the surface albedo to 100% of solar light.

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(D) Buffering temperature and reducing moisture loss.

2025

222. What is "phenotypic plasticity" in the context of breeding for climate resilience?
(A) The physical coating of seeds in plastic polymers.
(B) The inability of a genotype to survive any deviation.
(C) Genotype capacity to produce adaptive phenotypes.
(D) Strict determination of flowering based solely on age.

2003

223. How does the implementation of agroforestry (e.g., shade trees in coffee plantations) act as a potent microclimate modification technique under global warming?
(A) It intentionally starves the understory crop of light.
(B) It reduces canopy temperature and mitigates stress.
(C) It acts to trap enormous amounts of surface methane.
(D) It physically blocks all precipitation from the soil.

2004

224. Which physiological trait is actively selected for in crops to improve early vigor and rapid ground cover under climate-induced drought risk?
(A) Very low Specific Leaf Area (SLA) in the canopy.
(B) Complete lack of epicuticular wax on leaf surfaces.
(C) Extreme photoperiod sensitivity delaying emergence.
(D) Large seed size and high seedling growth rates.

2013

225. "Osmotic adjustment" is a critical genetic trait for drought and salinity resilience. This trait allows cells to maintain turgor by actively accumulating:
(A) Compatible solutes in the cytosol and vacuole.
(B) Heavy metal ions such as lead in the cell wall.
(C) Insoluble starch granules in the cell wall layers.
(D) Massive concentrations of reactive oxygen species.

NODIA

2023

226. What is the fundamental goal of "climate-smart" agricultural breeding?
(A) To breed crops strictly for maximum aesthetic appeal
(B) To develop varieties that entirely replace natural forest ecosystems
(C) To simultaneously sustainably increase productivity, enhance resilience (adaptation), and reduce or remove greenhouse gas emissions (mitigation)
(D) To create crops that require five times more synthetic nitrogen fertilizer

2009

227. Which advanced genetic tool is increasingly utilized to precisely introgress complex abiotic stress-tolerance QTLs (Quantitative Trait Loci) from wild relatives into modern elite crop cultivars?
(A) Marker-Assisted Selection (MAS) and genomic selection
(B) Visual selection based strictly on leaf color
(C) Random heavy-metal mutagenesis
(D) Exclusively grafting unrelated species

2016

228. Which of the following crop canopy architectures is most desirable for optimizing light distribution and reducing heat load in high-temperature, high-radiation environments?
(A) Horizontal, overlapping planophile leaves at the top.
(B) A completely leafless stem throughout the lifecycle.
(C) Massive, continuous leaves that carpet the soil surface.
(D) Erectophile leaf angles coupled with deep roots.

2003

229. The application of chemical anti-transpirants to foliage during a sudden, severe drought serves to modify the plant's physiological status by:
(A) Irreversibly destroying the stomatal guard cell units.
(B) Forming a physical film to reduce water loss.
(C) Acting as a nitrogen fertilizer absorbed via cuticle.
(D) Drastically increasing the rate of photorespiration.

2007

230. In evaluating the "ideotype" for a highly climate-resilient future wheat variety, which combination of traits would be considered most optimal?

(A) Shallow roots, massive unregulatable stomata, low sink strength, and heat-sensitive pollen
(B) Complete reliance on vernalization, inability to acclimate to UV-B, and high dark respiration
(C) Deep root architecture, stay-green capability, high intrinsic water use efficiency, and early morning anthesis to avoid peak daily temperatures
(D) Total absence of heat shock protein synthesis and an extremely long, extended vegetative phase

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ANSWERS

1. (A) Planetary albedo
Planetary albedo is the fraction of total incident solar radiation reflected from the Earth back into space. Surfaces like ice, snow, and clouds have high reflectance, significantly contributing to this value. This mechanism is crucial for regulating the Earth's energy balance by preventing the absorption of excessive shortwave radiation, thereby influencing the global climate system.

2. (C) It is primarily driven by anthropogenic halocarbon emissions.
The natural greenhouse effect is an atmospheric process that maintains the planet's average surface temperature at levels suitable for life. It primarily involves the absorption of outgoing infrared radiation by natural gases. While water vapor and carbon dioxide are the main drivers, anthropogenic halocarbons are synthetic pollutants and are not responsible for the natural version of this phenomenon.

3. (A) Variability involves short-term fluctuations, while change is a long-term shift.
Climate variability refers to short-term fluctuations in atmospheric conditions around a long-term mean, often occurring on seasonal or annual scales. In contrast, climate change represents a persistent, long-term shift in the state of the climate or its properties. Distinguishing between these two concepts is essential for understanding historical weather patterns and projecting future environmental trends across the globe.

4. (D) The specific state of the atmosphere at a given time and place.
Weather is defined as the specific state of the atmosphere at a particular time and place, encompassing short-term variables like temperature, humidity, and precipitation. Unlike climate, which represents the long-term average of these conditions over decades, weather describes instantaneous or daily atmospheric events. It is characterized by high volatility and is the primary focus of immediate meteorological observations.

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5. (B) Transferring surface energy to the atmosphere through water phase changes.
Latent heat flux is a fundamental component of the energy budget involving the transfer of energy from the Earth's surface to the atmosphere. This process occurs through the phase change of water, specifically evaporation from oceans and transpiration from vegetation. By moving energy without changing temperature during the phase transition, it plays a critical role in global heat distribution.

6. (C) It is continuously absorbed and re-emitted by gases in the troposphere.
Outgoing longwave radiation consists of thermal infrared energy emitted by the Earth's surface and atmosphere into space. As this radiation travels through the troposphere, it is continuously absorbed and re-emitted by greenhouse gases like carbon dioxide and methane. This interaction is the core mechanism of the greenhouse effect, as it traps energy within the lower atmosphere, regulating surface temperatures.

7. (D) Positive net radiative forcing at the tropopause.
The enhanced greenhouse effect alters the planetary energy budget by increasing the concentration of atmospheric gases that trap infrared radiation. This leads to a positive net radiative forcing at the tropopause, meaning less energy escapes to space than enters from the sun. Consequently, the surplus energy accumulates within the Earth system, causing a steady increase in global average temperatures.

8. (A) El Niño-Southern Oscillation (ENSO)
The El Niño-Southern Oscillation is considered an internal driver of climate variability because it arises from complex interactions within the Earth's climate system, specifically between the ocean and atmosphere. Unlike external forcings like volcanic eruptions or orbital changes, these oscillations represent natural, cyclical redistribution of heat. Understanding such internal processes is vital for predicting short-to-medium-term shifts in global weather.

44. (C) 8 to 14 μm
The atmospheric window refers to a specific range of infrared wavelengths, typically between 8 and 14 micrometers, where the atmosphere is relatively transparent. Most natural greenhouse gases like water vapor and carbon dioxide do not absorb strongly in this region. Consequently, energy in this range can escape directly into space, playing a vital role in cooling the Earth's surface.

45. (D) GWP20
The GWP20 metric is most appropriate for evaluating the immediate, short-term climatic impact of methane emissions. Because methane is a potent but short-lived gas, its warming influence is much higher over a twenty-year period compared to the standard one-hundred-year horizon. Focusing on shorter timeframes highlights the urgency of reducing methane to achieve rapid temperature stabilization goals in the near future.

46. (C) Anaerobic degradation of organic matter by Archaea
Methanogenesis in flooded paddy fields is a biological process carried out by anaerobic Archaea. These microorganisms decompose organic matter in the absence of oxygen, producing methane as a metabolic byproduct. The waterlogged conditions of rice cultivation create the perfect anaerobic environment for these organisms to thrive, making rice paddies a significant global source of atmospheric methane emissions.

47. (B) Mid-season drainage or Alternate Wetting and Drying (AWD)
Mid-season drainage or Alternate Wetting and Drying is the most effective strategy for mitigating methane emissions from rice cultivation. By periodically draining the fields, oxygen is introduced into the soil, which inhibits anaerobic methanogens and promotes the activity of methanotrophic bacteria that oxidize methane. This practice significantly reduces the total methane released without compromising the growth of the rice crop.

48. (D) Ruminal microbial fermentation of carbohydrates.
Enteric fermentation is a natural digestive process in ruminant livestock, such as cattle and sheep, where microbes break down complex carbohydrates in the rumen. Methane is produced as a byproduct of this microbial fermentation and is primarily released through eructation. Because of the vast number of livestock globally, this process represents one of the largest sources of anthropogenic methane emissions.

49. (A) I, III and V
In rice paddies, methanotrophic bacteria oxidize much of the produced methane, and rice plants facilitate its release through specialized aerenchyma tissue. In livestock, ionophores in feed can reduce methanogenesis by altering rumen microflora. However, high-tannin diets generally decrease rather than increase emissions, and nitrate application inhibits methanogenesis by acting as a preferred electron acceptor, making those statements incorrect.

50. (C) It acts as a passive pathway for soil methane release.
Aerenchyma tissue in rice plants consists of large air-filled spaces that allow for the diffusion of gases between the atmosphere and the roots. While this tissue is essential for supplying oxygen to submerged roots, it also acts as a passive conduit for methane to escape from the anaerobic soil. This pathway is responsible for the majority of methane emissions from rice paddies.

51. (A) High oxygen concentration (positive redox potential)
Methanogenic archaea are obligate anaerobes that require highly reduced conditions to function. The presence of oxygen, indicated by a positive redox potential, strictly inhibits their metabolic activity and methane production. Therefore, any agricultural practice that introduces oxygen into the soil, such as drainage or tillage, serves as an effective mechanism for suppressing methanogenesis in flooded field environments.

52. (D) Supplementing the diet with 3-NOP or red seaweed.
Supplementing cattle diets with compounds like 3-nitrooxypropanol or specific red seaweeds is a proven strategy for reducing enteric methane production. These additives work by directly inhibiting the enzymes involved in the final step of methanogenesis within the rumen. By reducing the amount of methane eructated, these

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fluctuations in polar regions and other glaciated areas across the globe.

18. (C) They are exclusively recovered from Arctic oceanic sea-ice.
Ice cores are vital for climate reconstruction, but they are not recovered from seasonal Arctic sea-ice, which is too thin and transient. Instead, they are extracted from massive, permanent ice sheets and glaciers in Antarctica and Greenland. These deep cores contain chronological layers of ice, volcanic ash, and trapped gases that provide a detailed history of the Earth's atmospheric conditions.

19. (A) Its annual ring width is highly sensitive to a specific climate variable, such as precipitation.
In dendroclimatology, a compliant tree species is one whose annual ring width shows high sensitivity to a specific limiting environmental factor, such as precipitation or temperature. These trees exhibit significant year-to-year variation in growth, providing a clear signal of climatic stress. This sensitivity is essential for developing chronologies that accurately reflect the historical climate of a particular geographic region.

20. (D) P-3, Q-2, R-1, S-4
Tree-ring features reveal specific physiological stresses throughout the growing season. Earlywood consists of wide, thin-walled cells formed in spring. Latewood contains narrow, dense cells produced in late summer. Frost rings occur due to unseasonal cold stress, while false rings result from temporary mid-season interruptions like drought. Identifying these structural anomalies allows for detailed reconstructions of past seasonal weather patterns.

21. (B) Matching patterns of wide and narrow rings across multiple trees to ensure exact temporal placement
Cross-dating is the fundamental principle of dendroclimatology, involving the matching of ring-width patterns among different trees from the same region. This technique ensures that each ring is assigned to its exact year of formation by identifying common markers of narrow or wide rings. It allows researchers to extend chronologies back in time and correct for missing or false rings.

22. (C) Solar eclipses : Primary cause of false ring formation
Tree growth is limited by various environmental factors; temperature dominates at treelines, while precipitation is the primary limit in arid zones. Defoliating insects can cause severe ring narrowing. However, solar eclipses are not a recognized cause of false ring formation. False rings are typically triggered by sudden, temporary physiological stresses such as mid-season droughts or unseasonal frosts during the growing period.

23. (D) The tree exhibits high year-to-year variability, reflecting strong climate responsiveness.
A high mean sensitivity index in a tree-ring chronology indicates that the tree exhibits significant year-to-year variability in its ring widths. This variation reflects a strong response to annual fluctuations in environmental conditions, making the tree an excellent proxy for climate reconstruction. Such trees are more useful for dendroclimatological studies than those with uniform, complacent growth patterns over time.

24. (A) Consistent, uninterrupted optimal growing conditions
False rings are anatomical anomalies that resemble true annual boundaries, usually triggered by environmental interruptions like summer droughts or late frosts. Consistent and uninterrupted optimal growing conditions are least likely to produce these features, as the tree maintains a steady physiological state throughout the season. These stable conditions result in uniform cell development rather than the sudden changes required for false rings.

25. (B) Standardization
Standardization is the process of removing non-climatic biological trends from raw tree-ring measurements, such as the natural decline in ring width as a tree ages. By fitting a mathematical curve to the data and calculating indices, researchers isolate the climatic signal. This procedure is essential for ensuring that the resulting chronology accurately reflects environmental variations rather than internal growth dynamics.

26. (B) Vessel element size and distribution
In angiosperm trees, the size and distribution of vessel elements are critical anatomical features

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for analyzing past hydrological changes. Because these cells are responsible for water transport, their development is highly sensitive to soil moisture availability and atmospheric demand. By studying variations in vessel diameter and density across annual rings, scientists can reconstruct historical patterns of rainfall and drought.

27. (A) Multi-century reconstructions of drought indices.
Dendroclimatology contributes uniquely to hydrological modeling by providing multi-century reconstructions of drought and streamflow indices. These long-term records extend beyond the limited timeframe of instrumental data, allowing for a better understanding of natural hydrological variability. This information is crucial for water resource management, assessing long-term climate risks, and validating the performance of complex regional climate models.

28. (C) Rubisco exhibits a kinetic isotope effect, preferentially fixing the lighter $^{12}CO_2$ molecule.
Carbon isotopic fractionation during photosynthesis is primarily caused by the kinetic isotope effect of the enzyme Rubisco. This enzyme exhibits a strong preference for the lighter ^{12}C isotope over the heavier ^{13}C isotope during the fixation of carbon dioxide. Consequently, plant tissues contain a lower ratio of ^{13}C to ^{12}C compared to the surrounding atmosphere, reflecting this internal biochemical discrimination.

29. (D) C_3 pathway
The C_3 photosynthetic pathway typically exhibits the most negative stable carbon isotope ratio, ranging from approximately -22 to -34 per mil. This is due to the strong discrimination by the enzyme Rubisco against the heavier ^{13}C isotope. In contrast, C_4 and CAM plants have less negative values because their initial carbon fixation mechanisms involve enzymes with lower isotopic discrimination.

30. (B) I and III
C_4 plants have less negative carbon isotope values than C_3 plants due to different initial fixation enzymes. Additionally, when C_3 plants close their stomata during drought, the internal concentration of carbon dioxide decreases, leading to less discrimination and a less negative isotope ratio. While Rubisco discriminates strongly, phosphoenolpyruvate carboxylase actually discriminates less, making the second statement in the series incorrect.

31. (B) A shift from C_3 to C_4 dominated vegetation.
A sudden positive shift in the carbon isotope value of soil organic matter typically indicates a historical transition from C_3-dominated vegetation to C_4-dominated species. Since C_4 plants are less depleted in the heavier ^{13}C isotope, their residues increase the overall isotope ratio of the soil. Such shifts often reflect changes in regional climate, particularly toward warmer or more arid conditions.

32. (D) It has become more negative due to fossil fuel combustion.
Since the Industrial Revolution, the stable carbon isotope signature of atmospheric carbon dioxide has become increasingly negative. This trend, known as the Suess effect, is primarily caused by the combustion of fossil fuels. Because fossil fuels are derived from ancient organic matter that was already depleted in ^{13}C, their release into the atmosphere dilutes the concentration of the heavier isotope.

33. (A) Intrinsic water use efficiency (iWUE).
The measurement of carbon isotope ratios in tree rings is used as a proxy for intrinsic water use efficiency, which is the ratio of photosynthesis to stomatal conductance. As stomata close to conserve water, the internal carbon dioxide concentration drops, reducing isotopic discrimination. By analyzing these ratios across rings, researchers can track how plants have historically adjusted their water usage.

34. (C) $\delta^{13}C = \left[\frac{\left(\frac{^{13}C}{^{12}C}\right)_{sample}}{\left(\frac{^{13}C}{^{12}C}\right)_{standard}} - 1\right] \times 1000$
The stable carbon isotope ratio is mathematically defined as the per mil deviation of the sample's ^{13}C to ^{12}C ratio from a recognized standard. The formula subtracts one from the ratio of the sample over the standard and multiplies the result by one thousand. This standardized notation allows researchers to compare isotopic data across different studies and environmental contexts with precision.

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35. (A) Internal Rubisco is forced to fix available ^{13}C.
C_4 plants exhibit significantly less isotopic discrimination than C_3 plants because their internal Rubisco enzymes are located in bundle sheath cells where carbon dioxide is highly concentrated. This physiological mechanism forces Rubisco to fix whatever carbon is available, including the heavier ^{13}C isotope. Consequently, the initial discrimination by phosphoenolpyruvate carboxylase, which is much lower than Rubisco, dominates the final signature.

36. (D) It increases due to higher intercellular CO_2 levels.
Under elevated atmospheric carbon dioxide levels without water stress, the isotopic discrimination in C_3 plants typically increases. Higher ambient CO_2 concentrations lead to higher intercellular CO_2 levels relative to the atmosphere, allowing Rubisco more opportunity to discriminate against the heavier ^{13}C isotope. This results in a more negative carbon isotope ratio in the newly synthesized plant tissues and biomass.

37. (B) Global Warming Potential (GWP)
Global Warming Potential is a metric used to compare the total energy absorbed by a specific greenhouse gas over a defined timeframe relative to carbon dioxide. It accounts for both the radiative efficiency and the atmospheric lifetime of the gas. This index is fundamental for climate policy, as it allows for the standardization of different emissions into carbon dioxide equivalents.

38. (B) $CO_2 < CH_4 < N_2O < CFC-12$
On a 100-year time horizon, greenhouse gases vary significantly in their warming influence. Carbon dioxide serves as the baseline with a value of one. Methane and nitrous oxide have much higher potentials due to their greater radiative efficiency. Chlorofluorocarbons like CFC-12 have the highest potentials, thousands of times greater than carbon dioxide, because they are extremely effective at trapping heat.

39. (C) I and IV
Nitrous oxide has an atmospheric lifetime of over a century, which is much longer than the roughly twelve-year lifetime of methane. Additionally, carbon dioxide does not have a single, specific lifetime because it is cycled through multiple reservoirs at varying rates. In contrast, methane is indeed removed primarily by hydroxyl radicals, and halocarbons possess higher radiative efficiencies than carbon dioxide.

40. (A) Nitrous oxide (N_2O)
Nitrous oxide is a unique greenhouse gas because it is chemically inert in the troposphere. Its primary removal mechanism is transport into the stratosphere, where it undergoes photolysis and reacts with excited oxygen atoms. This process is the only significant sink for nitrous oxide, contributing to its long atmospheric lifetime and making it a major contributor to both warming and ozone depletion.

41. (A) Both A and R are true and R is the correct explanation of A.
Radiative forcing is a standardized metric that measures the net change in the Earth's energy balance caused by a specific perturbation, such as increased greenhouse gas levels. Because it quantifies the difference between incoming solar radiation and outgoing infrared radiation, it provides a clear way to compare the warming impact of different substances. Both the assertion and its explanation are correct.

42. (B) Agricultural application of synthetic nitrogen fertilizers
The primary anthropogenic source of atmospheric nitrous oxide is the agricultural application of synthetic nitrogen fertilizers. In the soil, microbial processes such as nitrification and denitrification convert excess nitrogen into nitrous oxide gas. As global agricultural production has expanded, these emissions have increased significantly, making the management of nitrogen use a priority for mitigating climate change and protecting the ozone layer.

43. (A) Strong window absorption and long lifetimes.
Fully fluorinated compounds and sulfur hexafluoride have exceptionally high Global Warming Potentials due to their extreme stability and long atmospheric lifetimes. They possess strong absorption bands within the atmospheric window, allowing them to trap heat that would otherwise escape to space. Because they can persist in the atmosphere for thousands of years, their cumulative impact on the climate is enormous.

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9. (B) Troposphere
The troposphere is the lowest layer of the atmosphere where the natural greenhouse effect is most concentrated. This layer contains the highest density of air and the majority of atmospheric water vapor and carbon dioxide. Because these gases effectively absorb and re-emit terrestrial infrared radiation, the troposphere acts as a thermal blanket, maintaining the temperatures required for biological life on Earth.

10. (B) Both A and R are true but R is not the correct explanation of A.
Ice core records serve as highly accurate proxies for historical atmospheric composition because they contain trapped air bubbles representing ancient atmospheres. While the assertion regarding their accuracy is true, the reason involving isotopic composition reflects local temperature rather than explaining the proxy mechanism for carbon dioxide. Both statements provide valid paleoclimatic information, yet they describe distinct aspects of analysis.

11. (A) Pollen analysis (Palynology)
Pollen analysis, or palynology, is a paleoclimatological technique used to reconstruct past vegetation and regional climate patterns. Because pollen grains are resistant to decay and possess unique morphological features, they can be identified from lake and bog sediments. Changes in pollen assemblages over time allow scientists to infer shifts in plant communities, which directly correspond to historical climate variations.

12. (C) Oxygen isotope ratios ($\frac{^{18}O}{^{16}O}$) in foraminifera.
Historical sea surface temperatures are estimated by analyzing oxygen isotope ratios ($\frac{^{18}O}{^{16}O}$) found in the calcium carbonate shells of foraminifera. These marine organisms incorporate isotopes from seawater into their shells at rates dependent on the ambient temperature. By measuring these ratios within oceanic sediment layers, researchers can reconstruct past oceanic conditions and gain insights into long-term global climate trends.

13. (D) Tree rings : Annual
Tree rings are a unique paleoclimatic proxy because they provide annual temporal resolution, allowing for precise dating of past environmental conditions. Each year, trees produce a new layer of wood, the characteristics of which reflect the temperature and moisture availability of that specific growing season. This high-resolution data is invaluable for reconstructing climate history over the last several thousand years.

14. (C) High susceptibility to modern halocarbon contamination
While pollen analysis is a robust tool, it is limited by factors such as differential preservation and the overrepresentation of wind-pollinated species. However, modern halocarbon contamination is not a common limitation of this method, as halocarbons are synthetic chemicals that do not interfere with the biological morphology or stratigraphic placement of ancient pollen grains. Accuracy depends primarily on taxonomic identification.

15. (C) P-4, Q-1, R-2, S-3
Paleoclimatological methods target specific materials to reconstruct history. Dendroclimatology utilizes annual growth rings in trees to determine past climates. Palynology focuses on spores and micro-gametophytes preserved in sediments. Ice core analysis relies on trapped air bubbles for atmospheric data. Sedimentology examines materials like foraminifera and varves. Together, these multidisciplinary approaches provide a comprehensive understanding of the Earth's long-term environmental evolution.

16. (D) Winter deposition of fine organic matter and clay
Varves are annual sedimentary layers found in glacial or temperate lakes, consisting of distinct light and dark bands. The darker bands are primarily formed during the winter when the lake surface freezes, allowing fine organic matter and clay particles to settle slowly. This seasonal deposition pattern provides a chronological record that scientists use to analyze past hydrological and climatic changes.

17. (A) Local precipitation temperature
By analyzing the ratio of deuterium to hydrogen in ice cores, scientists can infer the local precipitation temperature at the time the snow fell. Lighter isotopes evaporate and condense differently than heavier ones, a process governed by temperature. This isotopic fractionation provides a reliable thermometer for reconstructing historical temperature

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interventions help lower the overall greenhouse gas footprint of the livestock industry.

53. (B) It reduces methane production because sulfate-reducing bacteria outcompete methanogens for substrates.
The application of sulfate fertilizers generally reduces methane production in flooded soils. This occurs because sulfate-reducing bacteria are more energetically efficient than methanogens and can outcompete them for common substrates like hydrogen and acetate. By shifting the microbial competition in the anaerobic soil, sulfate application effectively suppresses the rate of methanogenesis and subsequent atmospheric emissions from rice fields.

54. (C) It can lead to a significant increase in N_2O emissions.
While mid-season drainage is highly effective at reducing methane emissions, a significant disadvantage is the potential for increased nitrous oxide emissions. The transition between anaerobic and aerobic conditions in the soil can stimulate nitrification and denitrification processes that produce nitrous oxide. This trade-off must be carefully managed to ensure that the overall global warming potential of the field is reduced.

55. (C) P-2, Q-1, R-3, S-4
Methane mitigation strategies target different mechanisms within the agricultural system. Alternate Wetting and Drying increases soil redox potential in paddies. 3-NOP supplementation inhibits specific enzymes in the ruminant digestive tract. Bio-covers on manure lagoons promote the oxidation of methane by bacteria. Composting manure maintains aerobic conditions, preventing the anaerobic decay that leads to methane formation in liquid storage systems.

56. (A) The Navier-Stokes equations for fluid dynamics
General Circulation Models are complex computer simulations that represent the Earth's climate system based on fundamental physical laws. Their mathematical foundations are primarily built upon the Navier-Stokes equations, which describe the motion of fluid substances like air and water. By solving these equations across a global grid, GCMs can predict the circulation patterns of the atmosphere and oceans.

57. (B) Time-dependent projections of radiative forcing.
Representative Concentration Pathways describe specific time-dependent trajectories of atmospheric radiative forcing. Unlike earlier scenarios that focused primarily on socio-economic assumptions, RCPs provide a range of possible future energy imbalances in the Earth system. They serve as standardized inputs for climate models, allowing researchers to explore the environmental consequences of different levels of greenhouse gas concentrations through 2100.

58. (B) A radiative forcing of 8.5 W/m² relative to pre-industrial levels by the year 2100
In the RCP 8.5 scenario, the numeric value signifies a radiative forcing of 8.5 Watts per square meter by the year 2100, relative to pre-industrial levels. This specific pathway represents a high-emissions scenario where greenhouse gas concentrations continue to rise without significant mitigation efforts. It is often used to assess the potential "worst-case" impacts of climate change on global systems.

59. (A) They lack the ability to capture localized climate features.
A fundamental limitation of coarse-resolution General Circulation Models is their inability to capture localized climate features, such as topographical effects or small-scale weather patterns. While they are excellent for simulating global trends, their grid cells are often too large for precise agricultural planning at the regional level. This necessitates the use of downscaling techniques to provide more detailed data for local impacts.

60. (D) II, IV, I, III
Regional climate prediction follows a logical sequence. First, appropriate RCP scenarios are selected to define future forcing. Next, a General Circulation Model is run to simulate global responses. These outputs are then downscaled using regional models or statistical methods to gain localized data. Finally, this high-resolution climate information is used as input for agricultural impact models to assess crop performance.

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61. (D) They exclusively prescribe fossil fuel emissions and ignore land-use changes.
Representative Concentration Pathways are comprehensive and do not exclusively prescribe fossil fuel emissions while ignoring land-use changes. Instead, they integrate various factors, including greenhouse gas concentrations, air pollutants, and changes in land cover that affect the Earth's energy balance. They are designed to provide a wide range of plausible futures for scientific research and climate policy analysis.

62. (C) Downscaling
Downscaling is the process of deriving high-resolution local climate data from the relatively coarse outputs of General Circulation Models. This technique is essential for translating global climate projections into a scale that is meaningful for regional impact assessments, such as predicting changes in local rainfall or temperature. It can be achieved through either dynamic regional modeling or various statistical approaches.

63. (B) By systematically evaluating and comparing the performance of various GCMs under standardized conditions
The Coupled Model Intercomparison Projects enhance the reliability of climate predictions by systematically evaluating the performance of numerous global climate models under standardized conditions. By comparing how different models respond to the same scenarios, researchers can identify common trends, quantify uncertainties, and improve the overall accuracy of global warming projections used by international climate assessments.

64. (D) It amplifies surface warming by trapping longwave radiation.
Positive cloud-radiation feedback occurs when changes in cloud cover amplify surface warming. For example, if warming leads to an increase in high-altitude clouds that trap more outgoing longwave radiation than the sunlight they reflect, the initial warming is reinforced. This feedback is a major source of uncertainty in climate models, as it significantly influences the projected sensitivity of the global temperature.

65. (A) Elevated CO_2 reducing photorespiration in C_3 plants.
The carbon fertilization effect refers to the increase in the net photosynthetic rate of plants due to elevated atmospheric carbon dioxide. In C_3 plants, higher CO_2 levels competitively suppress the oxygenase activity of Rubisco, thereby reducing photorespiration. This allows the plant to assimilate more carbon into biomass, potentially leading to increased growth and yield, provided that other resources are available.

66. (C) The C_4 mechanism already saturates Rubisco with CO_2.
C_4 plants generally show a diminished growth response to elevated CO_2 compared to C_3 plants because their internal anatomy already concentrates CO_2 around the Rubisco enzyme. This mechanism ensures that Rubisco is near saturation even at current atmospheric levels. Therefore, increasing ambient CO_2 provides little additional benefit to the photosynthetic rate, although it may still improve the plant's overall water status.

67. (A) Competitively suppressed, favoring carboxylation.
Under elevated atmospheric carbon dioxide concentrations, the oxygenase activity of the Rubisco enzyme in C_3 plants is competitively suppressed. Because CO_2 and oxygen compete for the same active site on the enzyme, a higher ratio of CO_2 to O_2 favors the carboxylation reaction. This suppression of photorespiration is the primary mechanism through which increased CO_2 stimulates the growth of C_3 species.

68. (D) Its low affinity (high K_m) for CO_2 relative to ambient atmospheric concentrations
The differential response of C_3 and C_4 plants to elevated CO_2 is rooted in Rubisco's low affinity for CO_2 relative to modern atmospheric levels. In C_3 plants, the enzyme's high Michaelis constant (K_m) means it is not fully saturated, leaving it susceptible to oxygen fixation. C_4 plants overcome this limitation by physically concentrating CO_2, rendering the enzyme's low affinity irrelevant at higher ambient concentrations.

69. (D) II and III
While photosynthetic acclimation is a common long-term response to high CO_2, elevated CO_2 actually increases the optimal temperature for photosynthesis rather than decreasing it. Furthermore, carbon fertilization does not alleviate all nutrient limitations; in fact, it often exacerbates nitrogen deficiency as the plant's demand for nutrients increases with its

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accelerated growth rate, making both these statements factually incorrect.

70. (C) Non-structural carbohydrate buildup repressing Rubisco genes.
Photosynthetic acclimation or down-regulation during long-term exposure to elevated CO_2 is primarily driven by the buildup of non-structural carbohydrates in leaf tissues. When the production of sugars exceeds the capacity of the plant's sinks to utilize or export them, these sugars trigger a signaling pathway that represses the genes responsible for Rubisco synthesis. This feedback mechanism balances carbon supply with demand.

71. (C) I, II, III, IV
When a C_3 leaf is exposed to elevated CO_2 , a clear sequence of events occurs. First, the intercellular CO_2 concentration increases. This leads to the competitive inhibition of Rubisco's oxygenase activity, which subsequently decreases the rate of photorespiration. The final result of these biochemical shifts is a measurable increase in the net carbon assimilation rate, stimulating the plant's overall growth potential.

72. (A) Triticum aestivum (Wheat)
Among major crops, wheat (a C_3 species) is likely to exhibit the highest percentage increase in biomass from a doubling of atmospheric CO_2 . Unlike C_4 crops such as maize, sorghum, and sugarcane, wheat's photosynthetic rate is not saturated at current CO_2 levels. Therefore, it benefits more directly from the reduction in photorespiration and the enhancement of carbon fixation provided by higher CO_2 concentrations.

73. (B) Progressive nitrogen limitation in soil nutrient pools.
The initial stimulation of photosynthesis by elevated CO_2 often diminishes over time in natural ecosystems due to progressive nitrogen limitation. As plants grow faster and accumulate more carbon, they deplete the available soil nitrogen pools. Without sufficient nitrogen to build more photosynthetic machinery and tissues, the plant's ability to maintain higher rates of productivity is constrained, leading to a leveling off of response.

74. (B) Partial stomatal closure, reducing conductance.
Elevated atmospheric CO_2 typically induces partial stomatal closure in most plant species. This physiological response reduces stomatal conductance, which helps the plant conserve water by decreasing transpirational loss. Because the higher external concentration allows for sufficient CO_2 influx even with narrower openings, the plant can maintain or even increase its photosynthetic rate while significantly improving its overall water status.

75. (A) It decreases transpiration per leaf area, conserving moisture.
The interaction between elevated CO_2 and reduced stomatal conductance generally leads to a decrease in transpiration per unit of leaf area. By narrowing the stomatal pores, the plant limits the amount of water vapor escaping into the atmosphere. This "water-saving effect" is a significant benefit of high CO_2, as it can alleviate drought stress and improve the moisture balance within the plant.

76. (C) Photosynthetic carbon assimilation to stomatal conductance or transpiration
At the leaf level, Water Use Efficiency is defined as the ratio of photosynthetic carbon assimilation to the amount of water lost through transpiration or stomatal conductance. It measures how effectively a plant can fix carbon for every unit of water it spends. Improving this ratio is a key objective in breeding for drought-resilient crops in the face of changing climate conditions.

77. (D) WUE increases due to reduced stomatal conductance.
In C_4 crops, Water Use Efficiency increases under elevated CO_2 primarily due to reduced stomatal conductance. While their photosynthetic rates remain relatively stable because they are already CO_2-saturated, their stomata still close partially in response to higher ambient CO_2 levels. This reduction in transpirational water loss, combined with steady carbon gain, results in a more efficient use of available water resources.

78. (B) I and II
Research shows that elevated CO_2 can lead to a decrease in stomatal density in new leaves over several generations. Furthermore, while single-leaf transpiration decreases, the overall increase in leaf area index under high CO_2 can

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are essential for surviving in environments with high solar radiation.

133. (B) DNA and aromatic amino acids in proteins
DNA and aromatic amino acids within proteins strongly absorb radiation in the UV-B range. This absorption leads directly to structural deformations and chemical changes that can impair the function of these critical macromolecules. Because these components are fundamental to every cellular process, from replication to metabolism, their protection is a primary focus of the plant's various defense mechanisms.

134. (C) UVR8
UVR8 is a specific photoreceptor that mediates the plant's physiological and morphological responses to UV-B light. When it absorbs UV-B, it undergoes a structural change that initiates a signaling cascade, leading to the expression of genes involved in UV protection and repair. This receptor allows plants to sense and acclimate to their light environment, enhancing resilience to damaging radiation.

135. (D) Inhibition of PSII electron transport.
The UV-B-induced destruction of the D_1 protein in the chloroplast results in the inhibition of Photosystem II electron transport. As the D_1 protein is a central component of the PSII reaction center, its degradation disrupts the entire photosynthetic process. This damage reduces the plant's ability to convert light energy into chemical energy, leading to a decline in growth and productivity.

136. (A) Extreme enhancement of the carbon fertilization effect
Recognized consequences of elevated UV-B exposure include increased epidermal secondary metabolites, reduced biomass, and a higher incidence of DNA damage. However, UV-B does not enhance the carbon fertilization effect; in fact, it often works in opposition to the benefits of high CO_2 by damaging the photosynthetic apparatus. Therefore, the statement regarding the enhancement of carbon fertilization is the incorrect exception.

137. (A) III, I, II, IV
The UV-B signal transduction pathway follows a specific sequence. It begins with the absorption of UV-B by UVR8 homodimers, which then monomerize. These monomers interact with the COP1 protein, a key regulator in light signaling. Finally, this interaction activates transcription factors like HY5, which initiate the expression of genes required for the plant's acclimation and protection against ultraviolet solar radiation.

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138. (B) Photolyase and blue/UV-A light (350-450 nm)
Photoreactivation is a DNA repair mechanism that strictly requires the enzyme photolyase and blue or UV-A light for activation. The enzyme binds to the UV-B induced pyrimidine dimers and uses light energy to break the abnormal covalent bonds, restoring the original DNA structure. This direct repair pathway is highly efficient and is a primary defense for plants continuously exposed to sunlight.

139. (A) NER is a light-independent dark repair mechanism.
Nucleotide Excision Repair differs from photoreactivation because it is a "dark repair" mechanism that does not require light for activation. While photoreactivation uses photolyase to directly reverse a dimer, NER involves a multi-enzyme complex that excises a short section of the damaged DNA strand and synthesizes a new one. This allows the plant to repair DNA damage even in darkness.

140. (C) Cyclobutane pyrimidine dimers (CPDs)
The enzyme photolyase specifically targets cyclobutane pyrimidine dimers, which are the most common lesions caused by UV-B radiation. By binding to these sites, the enzyme can use energy captured from blue light to reverse the damage. This process is essential for maintaining the integrity of the plant's genome, as it prevents the accumulation of mutations that could otherwise impair development.

141. (C) Dark repair pathways (NER) are entirely absent in higher plants.
While photoreactivation is efficient and common in plants, the statement that dark repair pathways like Nucleotide Excision Repair are entirely absent in higher plants is incorrect. Plants possess a suite of both light-dependent and light-independent repair mechanisms to handle DNA damage. These pathways work together to ensure that genetic information is preserved despite the continuous stress of solar ultraviolet radiation.

Furthermore, increased carbon availability does not necessarily stimulate the simultaneous hyper-assimilation of nitrate; in many cases, it may actually inhibit nitrate reduction. Therefore, both the assertion and the reason provided are scientifically incorrect.

88. (A) Leaf-chewing insects due to reduced protein levels.
Leaf-chewing insects are most likely to be negatively impacted by the increased Carbon-to-Nitrogen ratio of plants grown under elevated CO_2. Because the protein content of the leaves is lower, these herbivores must consume more tissue to meet their nutritional requirements, which can slow their development and increase their exposure to predators. This shift in tissue quality alters food web dynamics.

89. (B) The mature, photosynthetically active flag leaf
During the grain-filling stage of cereal crops, the mature, photosynthetically active flag leaf acts as the primary "source" of carbon. It produces the majority of the sugars that are subsequently transported to the developing endosperm, which serves as the main "sink." The health and photosynthetic efficiency of the flag leaf are therefore crucial for determining the final weight and quality of the grain.

90. (B) The root system
Elevated CO_2 often alters the partitioning of biomass in agricultural crops, frequently leading to an increased allocation of carbon to the root system. By investing more resources into roots, plants may improve their ability to acquire water and nutrients, which are often the limiting factors for growth under stimulated carbon fixation. This shift is an important adaptive response to changing environmental conditions.

91. (A) Zinc and Iron
Zinc and Iron are the micronutrients most frequently reported to suffer significant concentration declines in edible grains under elevated CO_2. These reductions pose a major challenge for global food security and human nutrition, as billions of people rely on these crops as their primary source of essential minerals. Understanding the mechanisms behind these declines is critical for developing biofortified crop varieties.

92. (C) Increased fluidity and permeability of membranes.
At the cellular level, the initial physical disruption caused by acute high-temperature stress is an increase in the fluidity and permeability of biological membranes. As the lipid bilayer becomes too fluid, the structural integrity and selective barrier function of the membrane are compromised. This leads to the leakage of ions and solutes, disrupting the delicate chemical balance required for normal cellular metabolism.

93. (D) Heat Shock Proteins (HSPs)
Heat Shock Proteins are a specific class of molecules rapidly synthesized by cells in response to high temperatures. These proteins act as molecular chaperones, preventing other essential proteins from denaturing or forming toxic aggregates during stress. By assisting in the correct folding of proteins, HSPs play a vital role in maintaining cellular function and enabling plants to survive extreme heat events.

94. (A) P-4, Q-2, R-1, S-3
Cellular heat stress involves several key components. Heat Shock Factors bind to promoters to initiate gene transcription. Reactive Oxygen Species act as secondary messengers but can also cause oxidative damage. Superoxide Dismutase is an enzyme that scavenges harmful superoxide radicals. Chaperonins are specialized proteins that mediate the correct folding of denatured proteins. Together, these elements form the plant's complex defense system.

95. (B) Acquired thermo-tolerance
Acquired thermo-tolerance is the phenomenon where an initial, sub-lethal exposure to heat enables a plant to survive a subsequent, otherwise lethal heat shock. This process involves the rapid accumulation of protective molecules like heat shock proteins and antioxidants. It represents a fundamental adaptive mechanism that allows plants to prepare for and withstand the unpredictable temperature fluctuations common in many natural environments.

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96. (D) Hydrogen peroxide (H_2O_2)
Hydrogen peroxide (H_2O_2) is a relatively stable reactive oxygen species that can freely diffuse across cellular membranes. During temperature stress, it acts as a prominent signaling molecule, triggering the expression of various stress-responsive genes and defense pathways. However,

sometimes offset these savings, resulting in similar total canopy water use. Both statements accurately reflect the complex interactions between atmospheric CO_2 and plant hydrological dynamics.

79. (B) Alterations in ion channel activity (efflux of K^+ and anions) leading to reduced turgor pressure
Guard cells mediate stomatal closure under high CO_2 by altering the activity of ion channels in the plasma membrane. This leads to an efflux of potassium ions (K^+) and anions, which decreases the turgor pressure within the cells. As the guard cells lose their rigidity and deflate, the stomatal pore narrows, effectively restricting the passage of both carbon dioxide and water vapor.

80. (D) By increasing deep drainage and potential streamflow.
The "water-saving effect" of elevated CO_2 may influence regional hydrology by increasing deep drainage and potential streamflow. Because plants use less water and leave more moisture in the soil, more water is available to move into groundwater reserves or run off into river systems. This shifts the balance of the hydrological cycle, potentially altering water availability for both ecosystems and human use.

81. (A) Increased moisture retention via reduced transpiration.
In ecosystems dominated by C_3 woody shrubs, elevated CO_2 is likely to increase soil moisture retention. The reduction in transpirational water loss across the canopy means that less water is extracted from the soil profile over time. This conservation of moisture can have significant impacts on soil biology, groundwater recharge, and the survival of plant species during periods of low rainfall.

82. (A) Both A and R are true and R is the correct explanation of A.
Elevated carbon dioxide consistently improves the drought tolerance of C_3 crops by enhancing their water use efficiency. The primary reason for this is that decreased stomatal conductance reduces the rate of transpirational water loss. This allows the plants to maintain their hydration and physiological functions for longer periods when soil moisture is limited, effectively buffering them against the negative impacts of drought.

83. (A) The $C{:}N$ ratio increases due to enhanced carbon assimilation.
The tissue Carbon-to-Nitrogen ratio in C_3 plants typically increases under elevated atmospheric CO_2. This shift occurs because the stimulation of photosynthesis leads to a higher accumulation of carbon-rich compounds like sugars and starch, while nitrogen uptake often fails to keep pace. This change in tissue chemistry has wide-ranging implications for plant health, herbivory, and the nutritional quality of products.

84. (D) Excess biomass accumulation that dilutes protein levels.
The "dilution effect" in crops grown under elevated CO_2 refers to the decline in the concentration of proteins and essential minerals. This is primarily caused by the excess accumulation of biomass, specifically carbohydrates, which dilutes other nutrients within the plant tissue. As a result, even if the total amount of nutrients remains the same, their concentration per unit of weight decreases significantly.

85. (B) The capacity of non-photosynthetic organs (roots, tubers, grains) to import and utilize photoassimilates
Sink strength in plant physiology refers to the capacity of non-photosynthetic organs, such as roots, tubers, and developing grains, to import and utilize the sugars produced during photosynthesis. It is a critical factor in determining how a plant responds to elevated CO_2. If a plant has strong sinks, it can effectively use the additional carbon to increase its growth and yield.

86. (C) It results in leaf feedback inhibition of photosynthesis.
A severe limitation in a plant's sink capacity can lead to the feedback inhibition of photosynthesis under elevated CO_2. When the "sinks" cannot keep up with the increased supply of sugars from the "source" leaves, carbohydrates accumulate in the foliage. This buildup triggers a signaling cascade that down-regulates the expression of photosynthetic genes, preventing the plant from fully benefiting from higher CO_2.

87. (D) Both A and R are false.
Contrary to the assertion, elevated CO_2 generally decreases rather than enhances the protein concentration in wheat grains due to the dilution effect and reduced nitrogen assimilation.

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reducing the commercial value and quality of the harvest. Managing temperature during this critical period is essential for producing high-quality rice for consumers.

106. (B) By inhibiting lodicule swelling, keeping flowers closed.
Acute heat stress can disrupt anthesis by inhibiting the swelling of the lodicules, which are the small structures responsible for opening the flower. If the flowers remain closed, pollen cannot be released or captured, leading to poor pollination and reduced seed set. This mechanical failure is a primary reason why even brief periods of heat during flowering have devastating yield impacts.

107. (A) The lack of robust heat-shock protein synthesis capabilities in the mature microgametophyte
Pollen grains are highly susceptible to heat because they lack the ability to synthesize robust amounts of heat-shock proteins during their mature stage. Without these protective chaperones, the proteins within the microgametophyte are easily denatured, and the cell is prone to rapid dehydration. This biological limitation makes the survival of pollen a major bottleneck for plant reproduction under high-temperature conditions.

108. (C) Booting and early anthesis
Spikelet sterility in crops like rice is most directly correlated with temperature extremes occurring during the booting and early anthesis stages. During these periods, the reproductive organs are developing and preparing for fertilization, making them extremely sensitive to physiological disruptions. Heat stress at these specific times can prevent the formation of viable pollen or eggs, leading to empty grains.

109. (D) Advancing the date of bud burst and spring flowering.
A common adaptive phenological shift in wild plant species experiencing warmer regional climates is the advancement of the date of bud burst and spring flowering. By starting their reproductive cycle earlier in the season, these plants can avoid the increasingly extreme heat of late summer. This shift demonstrates the capacity of ecosystems to adjust to changing environmental cues despite potential ecological mismatches.

110. (C) Shriveled, low-test-weight grains
Terminal heat stress often causes a significant reduction in the grain-filling duration, resulting in shriveled grains with low test weight. When the period for accumulating starch and proteins is cut short, the grains do not reach their full potential size or density. This not only reduces the total yield but also degrades the nutritional and industrial quality of the harvested crop products.

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111. (C) II and III
Elevated CO_2 can sometimes ameliorate the negative impacts of moderate heat stress by providing more resources for the plant to use in repair and maintenance. Additionally, the combination of high CO_2 and high temperature often significantly accelerates phenological development, shortening the overall life cycle of the crop. While temperatures do affect respiration, they do not universally decrease its $Q_{\{10\}}$ value.

112. (D) It shifts higher due to suppressed photorespiration.
When plants are exposed to both elevated CO_2 and high temperatures, the optimal temperature for net photosynthesis typically shifts to a higher value. This occurs because elevated CO_2 suppresses photorespiration, which would otherwise increase rapidly with temperature. This shift allows the plant to maintain higher rates of carbon assimilation at warmer temperatures, potentially buffering some of the negative impacts of global warming.

113. (A) A shortened life cycle, reducing biomass accumulation.
Phenological acceleration under climate change scenarios primarily results in a shortened life cycle for the plant. By reaching reproductive maturity faster, the plant has less time for vegetative growth and the accumulation of biomass. In agricultural systems, this often translates to reduced yields, as the total duration for capturing solar energy and filling the grains is significantly compressed for the crop.

114. (C) CO_2 triggers closure, exacerbating leaf heat stress.
Elevated CO_2 generally triggers stomatal closure, which can exacerbate leaf heat stress by reducing the potential for transpirational cooling. While high temperatures would normally cause stomata

to open to cool the leaf, the presence of high CO_2 can override this signal. This interaction can lead to higher leaf temperatures and increased physiological stress, highlighting the complex trade-offs plants face in changing environments.

115. (A) Shortened grain-filling period and heat-induced spikelet sterility
When a crop faces both elevated CO_2 and severe terminal heat stress, the primary factors limiting productivity are the shortened grain-filling period and heat-induced spikelet sterility. Even if high CO_2 provides more carbon, the physical damage to the reproductive organs and the compression of the developmental timeline prevent the plant from converting that carbon into a larger harvest, nullifying the potential benefits.

116. (A) I, III and IV
Elevated CO_2 actually suppresses rather than enhances photorespiration at high temperatures. Furthermore, the interactive effects on crop yield are rarely just additive; they are often complex and antagonistic. Additionally, elevated CO_2 generally decreases rather than increases the $Q_{\{10\}}$ value of photorespiration. Only the statement regarding the fertilization effect being more pronounced at warmer temperatures is scientifically accurate in this list.

117. (B) The ecosystem shifts from being a carbon sink to a carbon source.
If warming-induced increases in soil respiration outpace the increases in net primary productivity stimulated by CO_2, the ecosystem will shift from being a carbon sink to a carbon source. This means the system will release more carbon into the atmosphere than it absorbs, creating a positive feedback loop that could further accelerate global warming. Monitoring these balances is crucial for terrestrial carbon cycle research.

118. (C) CO_2 reduces loss but higher temperatures increase demand.
The coupled impact of elevated CO_2 and elevated temperature on whole-plant water use is a balance of competing factors. While high CO_2 tends to reduce water loss through stomatal closure, higher temperatures increase the vapor pressure deficit and atmospheric demand for moisture. The final result depends on which factor dominates, but often the increased demand from heat offsets the savings from CO_2.

119. (D) Yield plummets as reproductive damage nullifies benefits.
When temperatures exceed the specific upper threshold for a crop cultivar, the reproductive damage caused by the heat often nullifies the potential benefits of elevated CO_2. The failure of pollination and the shortening of the developmental stages lead to a plummeting yield. This underscores the importance of developing cultivars that are not only responsive to CO_2 but also possess high thermal tolerance.

120. (A) Stratosphere
Chlorofluorocarbons are exceptionally stable in the troposphere, but they eventually migrate into the stratosphere. There, they are exposed to intense ultraviolet radiation, which provides the energy necessary for their photolytic decomposition. This breakdown releases chlorine atoms, which then initiate the catalytic cycles that lead to the destruction of the ozone layer, highlighting the long-range impact of these stable synthetic chemicals.

121. (B) Chlorine atom (Cl)
The catalytic destruction of stratospheric ozone by CFCs is primarily mediated by the release of chlorine atoms upon exposure to intense UV radiation. These free radicals are highly reactive and can break down ozone molecules through a series of chemical reactions. Because the chlorine is regenerated in each cycle, a single atom can destroy thousands of ozone molecules, thinning the ozone layer.

122. (A) $Cl + O_3 \rightarrow ClO + O_2$; $ClO + O \rightarrow Cl + O_2$
The primary catalytic cycle of ozone depletion by chlorine involves two steps. First, a chlorine atom reacts with ozone to form chlorine monoxide and oxygen. Then, the chlorine monoxide reacts with a free oxygen atom to regenerate the chlorine atom and produce another oxygen molecule. This cycle allows chlorine to continuously destroy ozone without being consumed, making it a highly efficient process.

123. (A) The presence of Polar Stratospheric Clouds (PSCs) and the isolated polar vortex
The massive, rapid formation of the "Ozone Hole" over Antarctica is driven by the presence of Polar Stratospheric Clouds and an isolated

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polar vortex. The vortex traps cold air, allowing PSCs to form during the dark winter. These clouds provide a surface for chemical reactions that convert inert chlorine reservoirs into active forms, which then rapidly destroy ozone after spring returns.

124. (C) They convert inert reservoirs into active chlorine.
Polar Stratospheric Clouds are critical to ozone depletion because they facilitate the conversion of inert chlorine reservoir compounds into active, ozone-destroying forms. During the cold Antarctic winter, chemical reactions on the surface of the cloud particles release chlorine gas. When spring arrives and sunlight returns, this gas is photolyzed into active chlorine radicals, leading to the rapid thinning of the ozone layer.

125. (D) Montreal Protocol
The Montreal Protocol is an internationally ratified treaty that has been highly successful in phasing out the production and use of chlorofluorocarbons and other ozone-depleting substances. By mandating the reduction of these chemicals, the protocol has allowed the ozone layer to begin its long recovery process. It is widely considered one of the most successful international environmental agreements in global history.

126. (C) Hydrochlorofluorocarbons (HCFCs)
Hydrochlorofluorocarbons were introduced as transitional replacements for CFCs because their hydrogen content makes them more reactive in the troposphere, leading to shorter atmospheric lifetimes. While they have a lower ozone depletion potential than CFCs, they are still potent greenhouse gases and contribute to ozone loss. Consequently, they are also being phased out in favor of more environmentally friendly chemical alternatives.

127. (B) Nitrogen oxides (NOx) cannot participate in catalytic ozone destruction cycles.
While stratospheric ozone is naturally created through the Chapman cycle and is most concentrated at 20-30 km, the statement that nitrogen oxides cannot participate in ozone destruction is incorrect. In fact, NOx compounds are major natural catalysts for ozone depletion. Additionally, the efficiency of chlorine atoms in destroying up to 100,000 ozone molecules is a well-established fact in atmospheric chemistry.

128. (D) A is false but R is true.
The assertion that the Antarctic ozone hole occurs primarily during the winter is false; the most severe depletion happens in the spring (September-October). However, the reason provided is true: the return of sunlight in the spring is strictly required to photolyze chlorine gas into the destructive radicals that drive the ozone-depletion cycles. Thus, while the timing is wrong, the chemical mechanism is correct.

129. (A) UV-C (100–280 nm)
UV-C radiation is the most energetic part of the ultraviolet spectrum and is entirely absorbed by the atmosphere, specifically by ozone and oxygen, before reaching the Earth's surface. Because of its high energy, it is extremely damaging to biological tissues and DNA. The atmosphere's ability to filter out this radiation is essential for protecting life on our planet from solar exposure.

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130. (C) Formation of cyclobutane pyrimidine dimers (CPDs) and 6-4 photoproducts
The most prominent, direct photobiological damage caused by elevated UV-B radiation is the formation of cyclobutane pyrimidine dimers and 6-4 photoproducts in the plant's DNA. These lesions occur when adjacent pyrimidine bases become covalently bonded, disrupting the double helix structure. If not repaired, these dimers can lead to mutations, impaired gene expression, and a measurable reduction in plant growth.

131. (B) 280–315 nm
The UV-B spectrum is defined as electromagnetic radiation with wavelengths between 280 and 315 nanometers. While it represents only a small fraction of the solar energy reaching the Earth, it is highly significant due to its potential for damaging DNA, proteins, and other cellular components. Changes in stratospheric ozone levels directly influence the amount of UV-B that reaches the surface.

132. (D) It causes stunting and increased leaf thickness.
Elevated UV-B radiation generally affects plant morphology by causing stunting and increasing leaf thickness. These changes are often considered adaptive responses that help the plant minimize UV exposure and protect its inner tissues. Other common responses include reduced leaf area and shorter internodes. While these modifications can lower productivity, they

if its concentration becomes too high, it can also lead to significant oxidative damage, making its regulation essential for the plant's long-term survival.

97. (A) Photosystem II (PSII), specifically the oxygen-evolving complex
The thermal stability of Photosystem II, specifically the oxygen-evolving complex, is notoriously vulnerable to high temperatures. Heat stress causes the dissociation of this complex and the damage of the D_1 protein, which severely limits the rate of electron transport in photosynthesis. Because PSII is a primary bottleneck, its failure often leads to a significant decline in the plant's overall productivity.

98. (C) It decreases to prevent excessive membrane fluidity.
During acclimation to chronically high temperatures, plants typically decrease the unsaturation level of their membrane lipids. By increasing the proportion of saturated fatty acids, they make the membranes more rigid, preventing the excessive fluidity that occurs at high temperatures. This structural adjustment helps maintain the integrity and function of cellular membranes, ensuring that essential physiological processes continue despite the heat.

99. (A) Malondialdehyde (MDA) content
Malondialdehyde content is a biochemical marker commonly measured to assess the extent of lipid peroxidation and oxidative membrane damage under stress. It is a byproduct of the breakdown of polyunsaturated fatty acids by reactive oxygen species. High levels of MDA indicate that the cellular membranes have been significantly compromised, making it a reliable indicator of the severity of heat-induced oxidative stress.

100. (D) I and III
Heat stress is a systemic issue that affects multiple organelles, including chloroplasts and mitochondria, not just the nucleus. Additionally, high temperatures generally increase the rate of dark respiration as metabolic demands rise, rather than decreasing it. While the unfolded protein response in the endoplasmic reticulum is a real stress reaction, the other two statements are fundamentally incorrect regarding plant physiology.

101. (B) Proline
Proline is a classic compatible osmolyte that plants accumulate during osmotic adjustment under various stresses, including high temperature. As a small, highly soluble molecule, it helps maintain cell turgor without interfering with normal metabolic processes. Beyond its role in osmoregulation, proline also acts as an antioxidant and a stabilizer for proteins and membranes, contributing to the plant's overall stress resilience.

102. (C) Anthesis (flowering and pollination)
Anthesis, the stage of flowering and pollination, is considered the most acutely sensitive reproductive stage in cereal crops to high-temperature stress. Even brief episodes of extreme heat during this period can lead to pollen sterility and poor fertilization, resulting in significant yield losses. This sensitivity makes anthesis a critical window for crop management and a major focus for breeding efforts.

103. (B) I, III and V
High temperatures generally decrease rather than increase pollen viability and tube growth. Warm night temperatures actually shorten the grain-filling duration, leading to lower yields. Furthermore, high temperatures can significantly impair the receptivity of female reproductive organs. While heat stress does cause anther indehiscence and sterile pollen, the other listed statements are incorrect based on established botanical research.

104. (A) Increased respiration leading to reduced grain weight.
High night temperatures during the grain-filling period lead to increased rates of dark respiration, which consumes the sugars that would otherwise be stored in the grain. This results in a reduction in final grain weight and overall yield. This phenomenon is a major concern for global food security, as nighttime temperatures are rising faster than daytime temperatures in many regions.

105. (B) Elevated temperatures during the grain-filling stage disrupting starch packing
Chalkiness in rice grains is primarily induced by elevated temperatures during the grain-filling stage, which disrupts the orderly packing of starch granules. These chalky areas are more brittle and likely to break during milling, significantly

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142. (C) DNA polymerase
In the dark repair pathway, specifically Nucleotide Excision Repair, DNA polymerase is responsible for synthesizing the new DNA strand. After the damaged oligonucleotide sequence containing the lesion is excised, the polymerase uses the intact complementary strand as a template to fill in the gap. This ensures that the genetic sequence is restored accurately before the final nick is sealed.

143. (B) Increased synthesis of protective screening compounds.
UV-B acclimation in plants is best demonstrated by the increased synthesis of protective screening compounds, such as flavonoids and phenolic esters. These molecules accumulate in the epidermal layers, where they absorb incoming UV-B radiation and prevent it from reaching the sensitive DNA and photosynthetic machinery in the mesophyll cells. This adaptive response significantly enhances survival in high-light environments.

144. (D) It fails to upregulate UV-absorbing flavonoids.
A mutant plant lacking a functional UVR8 gene fails to upregulate the synthesis of UV-absorbing flavonoids when exposed to UV-B radiation. Because it cannot sense the ultraviolet light, it does not initiate the signaling pathways required for acclimation. Consequently, these plants are much more susceptible to DNA damage and physiological stress, highlighting the critical role of the UVR8 receptor.

145. (A) P-3, Q-4, R-2, S-1
UV stress responses involve distinct molecular mechanisms. UVR8 activation involves tryptophan-mediated absorption that causes the receptor to monomerize. Photoreactivation relies on direct electron transfer from $FADH^-$ to reverse pyrimidine dimers. Nucleotide Excision Repair involves the excision of a short oligonucleotide sequence. Flavonoid synthesis leads to the accumulation of protective pigments in the vacuoles of epidermal cells, providing a comprehensive biological defense.

146. (A) Flavonoids (e.g., flavonols, anthocyanins) and sinapate esters
Flavonoids and sinapate esters are the primary classes of phenolic compounds that act as UV-B screens in the plant epidermis. These molecules possess specific chemical structures that allow them to absorb ultraviolet light while remaining transparent to the visible light needed for photosynthesis. By filtering out the most damaging wavelengths, they protect the internal cellular components from oxidative stress and genetic damage.

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147. (A) Ferulic acid
Ferulic acid is a common phenolic acid found in the cell walls of many plants, particularly grasses, where it acts as a primary UV-B screening compound. Beyond its role in structural support, its ability to absorb ultraviolet radiation helps shield the plant from solar damage. This multifunctional nature of phenolic acids demonstrates how plants have evolved complex biochemical strategies to cope with environmental stressors.

148. (D) The central vacuole
UV-screening flavonoids primarily accumulate in the central vacuole of epidermal cells. This location allows them to form a protective layer that intercepts incoming ultraviolet radiation before it can penetrate into the underlying tissues. By concentrating these pigments in the vacuole, the plant maximizes their effectiveness as a biological filter while keeping them sequestered from the main metabolic pathways in the cytoplasm.

149. (B) They exhibit strong absorption squarely in the UV-B range.
Sinapate esters like sinapoyl malate are critical for UV protection in species such as Arabidopsis because they exhibit exceptionally strong absorption squarely in the UV-B range. These compounds are even more effective than many flavonoids at filtering out the most damaging wavelengths. Their presence in the epidermis provides a vital first line of defense, ensuring that the genetic systems remain functional.

150. (C) Phenylalanine ammonia-lyase (PAL)
Phenylalanine ammonia-lyase is the critical, rate-limiting enzyme that initiates the biosynthesis of all phenylpropanoids, including the flavonoids and phenolic acids used for UV protection. By converting phenylalanine into cinnamic acid, PAL directs carbon from primary metabolism into these essential secondary pathways. Its activity is strongly regulated by environmental cues like UV light, ensuring the plant can rapidly respond.

151. (D) Lignin : Exclusively for primary DNA repair
Anthocyanins, proline, and flavonols all have well-defined roles in UV-screening, osmotic adjustment, and cellular protection. However, lignin is primarily a structural component of cell walls and does not function in primary DNA repair. While it may provide some passive shielding, the statement linking it exclusively to DNA repair is factually incorrect, as that role is fulfilled by various enzymes.

152. (A) It protects their photosynthetic apparatus and DNA from the intense UV radiation characteristic of high altitudes.
The synthesis of UV-absorbing compounds provides a significant competitive advantage to alpine plants by protecting their DNA and photosynthetic apparatus from the intense radiation found at high altitudes. Without these chemical defenses, the high levels of solar UV would cause irreparable damage, limiting growth and survival. This biochemical adaptation is essential for the persistence of diverse plant communities in mountainous environments.

153. (B) Acting as potent antioxidants to scavenge reactive oxygen species (ROS)
A major secondary benefit of increased flavonoid accumulation is their role as potent antioxidants. Beyond their function as UV screens, they can scavenge reactive oxygen species that are generated during environmental stress. This dual role helps protect the cell from both direct radiation damage and the subsequent oxidative stress that can occur when metabolic processes are disrupted by heat or drought.

154. (B) I, II and V
UV-screening compounds are effective because they absorb UV-B while remaining transparent to photosynthetically active radiation. Chalcone synthase is indeed a key enzyme that directs carbon into the flavonoid pathway, and these compounds can attenuate up to 90% of incident UV-B. However, they are not transported into chloroplasts for DNA shielding, and their synthesis is upregulated by the UVR8 photoreceptor.

155. (A) The presence of a highly conjugated system of alternating double bonds and aromatic rings
The effectiveness of flavonoids as UV filters and antioxidants is due to their highly conjugated system of alternating double bonds and aromatic rings. This chemical structure allows the molecules to absorb energy from ultraviolet photons and dissipate it safely. It also enables them to stabilize free radicals, making them versatile tools for protecting plant cells from various types of light-induced damage.

156. (C) It strips the plant of its natural UV-B defenses.
Breeding programs that strictly reduce bitter phenolic compounds to improve the palatability of crop foliage may inadvertently decrease the plant's resilience. Many of these "bitter" substances are the very flavonoids and phenolic acids that provide natural UV-B defense. Stripping the plant of these compounds leaves it vulnerable to solar radiation, which can lead to reduced yields and increased stress sensitivity.

157. (D) To dissipate excess excitation energy safely as heat via non-photochemical quenching (NPQ)
The primary function of carotenoids during high-light or heat stress is to dissipate excess excitation energy safely as heat through non-photochemical quenching. This process prevents the energy from overwhelming the photosynthetic reaction centers and generating harmful reactive oxygen species. By acting as a safety valve, carotenoids protect the delicate machinery of the thylakoid membrane from being destroyed by solar energy.

158. (C) Violaxanthin, Antheraxanthin, and Zeaxanthin
The xanthophyll cycle strictly involves the enzymatic conversion between three specific molecules: violaxanthin, antheraxanthin, and zeaxanthin. This cycle allows plants to adjust their energy dissipation capacity in response to changing light levels. Under high light, violaxanthin is converted to zeaxanthin to increase heat dissipation, while in the dark or low light, the process is reversed to maximize photosynthetic efficiency.

159. (B) Zeaxanthin
Under severe excess light and climatic stress, zeaxanthin accumulates heavily in the thylakoid membrane. It is the most effective pigment in the xanthophyll cycle for mediating the thermal dissipation of excitation energy. By increasing the amount of zeaxanthin, the plant can safely handle levels of solar energy that would otherwise cause significant damage to the photosynthetic apparatus and lead to chronic photoinhibition.

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160. (D) A heavily acidified thylakoid lumen (low pH) resulting from excessive electron transport
The enzyme violaxanthin de-epoxidase is activated by a heavily acidified thylakoid lumen, which occurs when electron transport rates exceed the capacity of the Calvin cycle. This low pH signal tells the plant that it is receiving more energy than it can use for carbon fixation. The activation of VDE then triggers the conversion of violaxanthin to zeaxanthin, initiating protection.

161. (A) They stabilize lipid membranes and Light-Harvesting Complexes against oxidative destruction.
Beyond their role in photoprotection, carotenoids play a crucial structural role by stabilizing lipid membranes and light-harvesting complexes. Their presence within the thylakoid membrane prevents the oxidative destruction of these sensitive components by reactive oxygen species. This stabilization is essential for maintaining the integrity of the photosynthetic machinery under the stressful conditions of high light and high temperatures.

162. (B) II, III, I
The xanthophyll cycle progresses through three states as light levels increase. It starts with violaxanthin in the dark-adapted or low-light state. As light intensity rises, it is converted into the intermediate antheraxanthin. Under severe light stress, it is further converted into zeaxanthin, which provides maximum energy dissipation. This sequence allows the plant to finely tune its light protection based on environmental demands.

163. (A) By dissipating chlorophyll excitation energy as heat.
Zeaxanthin physically facilitates non-photochemical quenching by directly dissipating the excitation energy from chlorophyll as heat. When energy levels are too high, zeaxanthin interacts with the light-harvesting complexes to provide a pathway for the safe release of this energy. This mechanism is vital for preventing the over-reduction of the electron transport chain and the subsequent formation of damaging oxidative compounds.

164. (D) A sustained decrease in the quantum yield of PSII.
Photoinhibition is defined as a sustained decrease in the quantum yield of Photosystem II caused by exposure to excessive light energy. It occurs when the rate of light-induced damage to the photosynthetic machinery exceeds the plant's capacity for repair. This condition leads to a significant decline in photosynthetic efficiency and can severely limit plant growth and productivity under extreme climatic conditions.

165. (B) It depends on the stroma-based zeaxanthin epoxidase.
The recovery phase of the xanthophyll cycle, which involves converting zeaxanthin back to violaxanthin, is slower than the forward stress response because it depends on a different enzyme. This process is mediated by zeaxanthin epoxidase, which is located in the stroma and requires a higher pH to function optimally. The slow recovery ensures that the plant remains protected temporarily after stress.

166. (C) Elevated atmospheric trace gases (like CO_2 or O_3) on crops under semi-natural conditions
Open Top Chambers are specialized field structures used to study how elevated trace gases, such as carbon dioxide or ozone, affect plants under semi-natural conditions. By continuously pumping these gases into a chamber with an open top, researchers can simulate future atmospheric environments. This allows for the observation of crop responses to climate change within a controlled yet relatively realistic setting.

167. (D) They artificially alter the internal microclimate.
The most significant limitation of Open Top Chambers is the "chamber effect," where the physical structure artificially alters the internal microclimate. The walls of the chamber can reduce wind speed, increase humidity, and raise air temperatures compared to the open field. These artifacts can sometimes confound the experimental results, making it difficult to isolate the effects of the target gas.

168. (A) Using a forced airflow that is progressively heated.
Temperature Gradient Tunnels function by using a forced airflow that is progressively heated as it moves through a long, transparent structure. This establishes a continuous thermal gradient from one end of the tunnel to the other. By planting crops along this gradient, researchers can observe how different temperature levels affect plant growth and development simultaneously under the same ambient environmental conditions.

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169. (B) They perfectly replicate natural field microclimates without any artifacts.
Open Top Chambers are valuable because they are relatively inexpensive and allow for natural precipitation, but they do not perfectly replicate the natural field microclimate. The statement claiming they avoid all artifacts is incorrect, as the physical presence of the chamber inherently modifies variables like wind and temperature. Despite these "chamber effects," they remain a standard tool for exploring atmospheric changes on vegetation.

170. (B) I and II
Research confirms that OTCs suffer from chamber effects and that TGTs are exceptionally useful for establishing precise thermal gradients. However, the statement that OTCs eliminate boundary layer resistance is incorrect; the reduced wind inside the chambers often increases rather than decreases this resistance. Understanding these technical nuances is essential for correctly interpreting data from controlled climate change experiments on agricultural systems.

171. (A) The walls reduce wind and alter the boundary layer.
Estimations of evapotranspiration from OTC experiments may not perfectly extrapolate to open fields because the chamber walls reduce wind and alter the boundary layer. These changes can significantly decrease the rate of water loss from leaves compared to unconfined plants. Researchers must account for these microclimatic differences when using chamber data to model regional water use and future irrigation requirements.

172. (C) Chambers with ambient CO_2 blown in as a control
To calculate crop yield responses to elevated CO_2 in an OTC experiment, researchers must compare the results from the elevated chambers to chambers where ambient air is blown in. This "ambient control" is critical for separating the effects of the CO_2 from the microclimatic artifacts caused by the chamber structure itself. Using unchambered plots as the only control leads to inaccurate conclusions.

173. (D) TGTs provide a continuous temperature response curve.
The primary advantage of using a Temperature Gradient Tunnel over isolated growth chambers is that it provides a continuous temperature response curve. Instead of observing plants at only a few fixed temperature points, researchers can see how growth changes across a wide spectrum of thermal conditions. This detailed data is invaluable for identifying specific temperature thresholds and optimizing crop management strategies for global warming.

174. (C) Target gas concentration (e.g., CO_2) due to incursion of ambient air from the open top
On windy days, it is notoriously difficult to maintain uniform target gas concentrations within an Open Top Chamber. The incursion of ambient air from the open top can dilute the CO_2 or ozone being pumped in, leading to fluctuations that complicate the experimental design. Engineers must use sophisticated sensing and distribution systems to minimize these variations and ensure the validity of research.

175. (B) Free-Air CO_2 Enrichment
The acronym FACE stands for Free-Air CO_2 Enrichment. This technology represents an advanced method for studying the effects of elevated atmospheric carbon dioxide on entire ecosystems and crop canopies without the use of chambers. By enriching the air in an open-field setting, researchers can gain a more accurate understanding of how plants will respond to future atmospheric conditions in nature.

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176. (B) Releasing CO_2 from vent pipes using natural wind.
The fundamental engineering principle of a FACE system involves releasing carbon dioxide from a series of vent pipes surrounding a field plot. By using real-time wind data, the system only releases gas from the upwind pipes, allowing the natural wind to carry the CO_2 across the canopy. This method ensures that the plants experience elevated CO_2 without any structural confinement.

177. (A) Enrichment without altering the natural microclimate.
The primary scientific advantage of FACE technology over Open Top Chambers is its ability to provide CO_2 enrichment without altering the natural microclimate. Because there are no walls to block wind or trap heat, the experimental results are more representative of how plants will actually behave in a future high-CO_2 world. This realism makes FACE the standard for large-scale research.

178. (C) I and IV
FACE systems do not suffer from chamber effects because they are open to the atmosphere. Furthermore, they are specifically designed to study entire canopies and ecosystems rather than single plants. While they are expensive and can struggle with gas control under extreme wind conditions, the statements regarding chamber effects and plant isolation are incorrect. They provide realistic simulations of future conditions.

179. (A) The actual yield increase under open-field elevated CO_2 was often significantly lower than previously predicted by enclosure (OTC) studies.
A classic discovery from early FACE experiments was that the actual yield increase under open-field elevated CO_2 was often significantly lower than what had been predicted by earlier enclosure studies. This finding highlighted the importance of realistic microclimatic conditions in research. It showed that "chamber effects" in OTCs had likely led to an overestimation of the carbon fertilization effect on global productivity.

180. (D) It is controlled via real-time wind and sensor data.
The release of CO_2 in a standard FACE ring is controlled through a sophisticated system that uses real-time wind and sensor data. Computers monitor the wind direction and speed to determine which vent pipes should be active and how much gas to release. This dynamic control is necessary to maintain a stable target CO_2 concentration across the entire experimental plot.

181. (A) Both A and R are true and R is the correct explanation of A.
FACE experiments are ideally suited for studying large-scale ecosystem dynamics and biogeochemical cycling because they provide a realistic, open-air environment. They allow for the observation of entire crop canopies, deeply rooted trees, and undisturbed soil food webs under elevated CO_2. Both the assertion and its reasoning are correct, emphasizing why FACE is essential for understanding long-term climate change.

182. (C) Step-increase artifacts from sudden gas exposure.
A common limitation when interpreting FACE results is the presence of "step-increase artifacts" caused by the sudden exposure of plants to high gas levels. In the real world, CO_2 concentrations are rising gradually over decades, allowing plants and ecosystems time to acclimate. The rapid shift in FACE experiments may not perfectly capture the long-term evolutionary adjustments that will occur naturally.

183. (D) Progressive Nitrogen Limitation (PNL) in the soil
In long-term forest FACE experiments, the initial stimulation of carbon sequestration is often limited by Progressive Nitrogen Limitation. As the trees grow faster under high CO_2, they deplete the available nitrogen in the soil. Without enough nitrogen to build new tissues and maintain higher rates of photosynthesis, the growth response eventually levels off, highlighting the critical role of nutrient availability in ecosystems.

184. (A) Through open stomata during gas exchange
Atmospheric sulfur dioxide primarily enters the interior of a plant leaf through the open stomata during normal gas exchange. Once inside, it can interact with the delicate tissues of the mesophyll. While the waxy cuticle provides a barrier against many substances, it is relatively permeable to gases like SO_2, making the stomatal pathway the most significant route for this pollutant.

185. (B) It forms toxic sulfite ions and generates ROS.
Once sulfur dioxide dissolves in the aqueous film lining the mesophyll cell walls, it rapidly forms toxic sulfite ions and generates reactive oxygen species. These ions can disrupt various cellular processes, including photosynthesis and respiration, by damaging proteins and membranes. This biochemical shift is the primary cause of the phytotoxicity associated with acute exposure to high atmospheric sulfur dioxide.

186. (B) Interveinal, distinctly bleached (chlorotic or necrotic) lesions on mature leaves
Foliar necrosis from acute sulfur dioxide exposure typically presents as interveinal, distinctly bleached lesions on mature leaves. These spots or patches occur where the concentration of toxic sulfite has overwhelmed the cell's detoxification capacity. The damage is often most visible between the veins, where the tissue is furthest from the vascular system, providing a clear visual indicator of SO_2 pollution.

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the overgrowth of algae and cyanobacteria. This nutrient enrichment shifts the balance of the ecosystem, leading to a decline in water quality and aquatic biodiversity loss.

205. (D) Dying biomass decomposition consumes dissolved oxygen.
Explosive algal blooms during eutrophication create "dead zones" primarily because the decomposition of the massive amount of dying biomass consumes most of the dissolved oxygen in the water. As aerobic bacteria break down the algae, they deplete the oxygen levels to the point where fish can no longer survive. These anoxic conditions are a hallmark of severely eutrophied lakes and coastal areas.

206. (C) High turbidity, shallow photic zone, and frequent anoxic hypolimnion
A highly eutrophic lake is characterized by high turbidity, a shallow photic zone, and frequent anoxic conditions in the bottom water due to excessive nutrient loading. In contrast, oligotrophic lakes are nutrient-poor and have very clear water with high light penetration. The shift from an oligotrophic to a eutrophic state is a major ecological concern that often results from farming.

207. (B) They act as nutrient sinks, directly outcompeting phytoplankton for dissolved nitrogen and phosphorus.
Aquatic macrophytes play a crucial role in mitigating the effects of mild eutrophication by acting as natural nutrient sinks. They directly compete with phytoplankton for dissolved nitrogen and phosphorus, limiting the growth of harmful algal blooms. Additionally, these plants provide habitat for diverse aquatic organisms and help stabilize sediment, contributing to the overall stability and health of the freshwater ecosystem.

208. (D) High levels of Dissolved Oxygen (DO), typically above 5-6 mg/L
High levels of dissolved oxygen, typically above 5-6 mg/L, are a standard indicator of a healthy, unpolluted aquatic ecosystem. Adequate oxygen is essential for supporting a wide variety of aquatic fauna, including sensitive fish and invertebrate species. Maintaining these levels is a primary goal of water management and pollution control efforts, as oxygen-rich environments support significantly greater biological diversity.

209. (A) Heavy metals and metalloids (e.g., Chromium, Cadmium)
Industrial effluents from sectors like electroplating and leather tanning frequently introduce toxic heavy metals and metalloids into surrounding soils and water. Elements such as chromium, cadmium, and lead are persistent pollutants that can accumulate in agricultural land. Their presence poses a significant risk to crop health and food safety, as they can be taken up by plants easily.

210. (C) Binding to sulfhydryl groups and inhibiting enzymes.
Heavy metals like cadmium disrupt physiological functions within plant cells by binding to the sulfhydryl groups of proteins. This interaction can inhibit the activity of essential enzymes and disrupt the structural integrity of cellular components. The resulting metabolic imbalances lead to symptoms like chlorosis and stunted growth, as the plant struggles to maintain its normal biochemical processes under metal stress.

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211. (A) Biomagnification
Biomagnification is the process by which the concentration of certain pollutants, such as heavy metals or persistent organic chemicals, increases at successively higher levels of a food web. Organisms at the top of the chain, like predatory fish or birds, accumulate much higher concentrations than the surrounding environment or their prey. This phenomenon explains why low environmental pollution poses risks.

212. (D) Phytochelatins
Phytochelatins are a family of small, cysteine-rich peptides synthesized by plants to safely chelate toxic heavy metal ions. These peptides bind to metals like cadmium and lead in the cytosol and facilitate their transport into the central vacuole, where they are sequestered. This detoxification mechanism is essential for enabling plants to tolerate metal-contaminated environments and maintain growth despite harmful ions.

213. (B) They are completely biodegradable by natural soil bacteria within a few weeks.
Heavy metals are persistent environmental pollutants; they are not biodegradable and cannot be broken down by soil bacteria. While they can be transformed into different chemical forms, they remain in the ecosystem indefinitely. The other statements regarding their accumulation

stress. Recognizing these flecks is essential for identifying ozone pollution in fields.

196. (D) P-3, Q-1, R-4, S-2
Air pollutants have distinct effects on vegetation and ecosystems. Tropospheric ozone causes upper-surface flecking. Peroxyacetyl Nitrate induces a characteristic "glazing" on the lower leaf surface. Sulfur dioxide leads to interveinal bleached lesions on mature leaves. Acid rain, defined by a low pH, is responsible for mobilizing toxic aluminum in forest soils. This mapping is vital for diagnosing environmental damage from industrial sources.

197. (B) Collapses mesophyll cells, causing leaf bronzing.
Peroxyacetyl Nitrate is highly toxic to plants because it causes the collapse of mesophyll cells, resulting in a characteristic "bronzing" or "glazing" on the underside of the leaves. This secondary pollutant, formed in photochemical smog, interferes with cellular respiration and photosynthetic processes. Its presence in the atmosphere is a significant threat to crop productivity and forest health in urban regions.

198. (C) Salicylic acid and Ethylene/Jasmonic acid pathways
The salicylic acid, ethylene, and jasmonic acid signaling pathways are rapidly activated in plants in response to ozone-induced oxidative stress. These hormones coordinate the plant's defense response, which can include the synthesis of antioxidants and the induction of programmed cell death in affected areas. Understanding these molecular responses is key to developing more ozone-tolerant crop varieties for the future.

199. (D) Accelerated leaf senescence and reduced assimilation.
Chronic, low-level exposure to tropospheric ozone primarily reduces crop yield by accelerating leaf senescence and decreasing the overall rate of carbon assimilation. Even without visible symptoms, ozone-induced stress can lead to the premature aging of the foliage, shortening the period during which the plant can produce sugars for grain development. This hidden damage is responsible for significant global productivity losses.

200. (D) Both A and R are true and R is the correct explanation of A.
Elevated atmospheric CO_2 can often mitigate the damage caused by tropospheric ozone. The primary reason is that high CO_2 concentrations generally induce stomatal closure, which restricts the amount of ozone that can physically enter the leaf interior. By reducing the uptake of the pollutant, CO_2 provides a protective effect, illustrating the complex interactions between different atmospheric gases in determining plant health.

201. (B) Biological Oxygen Demand (BOD)
Biological Oxygen Demand is a critical metric that measures the amount of dissolved oxygen required by aerobic microorganisms to break down the organic matter in a water body over a specific period. It is used as a primary indicator of water quality and the level of organic pollution. High BOD values signify that a large amount of organic material is present.

202. (B) COD uses chemical oxidants to measure total oxidizable matter.
Chemical Oxygen Demand fundamentally differs from BOD because it uses strong chemical oxidants to measure the total amount of both organic and inorganic matter that can be oxidized in a water sample. Unlike BOD, which only accounts for biodegradable material, COD provides a faster and more comprehensive assessment of total oxygen demand, making it a valuable tool for monitoring wastewater.

203. (A) Severe depletion of Dissolved Oxygen (DO), leading to hypoxia and massive fish kills
Discharging effluents with high BOD into a water body leads to the severe depletion of dissolved oxygen as microorganisms consume it to decompose organic waste. This rapid drop in oxygen levels can cause hypoxia, which is lethal to fish and other aquatic organisms. These massive fish kills are a common and devastating environmental impact of poorly managed domestic and industrial wastewater.

204. (C) Nitrogen and Phosphorus
Nitrogen and phosphorus are the two macronutrients primarily responsible for driving cultural eutrophication in freshwater ecosystems. While these nutrients are existentially essential for life, their excessive accumulation from agricultural runoff and wastewater stimulates

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increasingly important as climate patterns become more unpredictable and extreme.

223. (B) It reduces canopy temperature and mitigates stress.
Agroforestry systems, like using shade trees in coffee plantations, act as potent microclimate modification techniques by reducing canopy temperatures and mitigating heat stress. The trees provide a protective overstory that filters intense sunlight and creates a cooler, more humid environment for the understory crops. This natural temperature management is a vital strategy for protecting sensitive crops from global warming impacts.

224. (D) Large seed size and high seedling growth rates.
Large seed size and high seedling growth rates are physiological traits selected for to improve early vigor and rapid ground cover. Under climate-induced drought risk, establishing a strong canopy quickly helps reduce soil evaporation and gives the plant a better chance of reaching deeper moisture. These traits are essential for ensuring crop establishment and survival in regions with unpredictable rainfall.

225. (A) Compatible solutes in the cytosol and vacuole.
Osmotic adjustment is a critical resilience trait that allows plant cells to maintain turgor under drought or salinity stress by accumulating compatible solutes. These small, non-toxic molecules, such as proline and sugars, increase the internal solute concentration, drawing water into the cell. This adjustment is vital for maintaining cellular functions like expansion and stomatal opening, enabling continued growth.

226. (C) To simultaneously sustainably increase productivity, enhance resilience (adaptation), and reduce or remove greenhouse gas emissions (mitigation)
The fundamental goal of climate-smart agricultural breeding is to develop crop varieties that simultaneously increase productivity, enhance resilience to climate change, and reduce greenhouse gas emissions. This multi-objective approach ensures that agriculture can sustainably feed a growing population while also contributing to global climate mitigation efforts. It represents a paradigm shift toward more holistic and sustainable systems.

227. (A) Marker-Assisted Selection (MAS) and genomic selection
Marker-Assisted Selection and genomic selection are advanced genetic tools used to precisely introgress complex stress-tolerance traits from wild relatives into modern crop cultivars. By using molecular markers to track specific genes or quantitative trait loci, breeders can develop more resilient varieties faster and with greater accuracy. These technologies are essential for keeping pace with rapid environmental changes.

228. (D) Erectophile leaf angles coupled with deep roots.
An erectophile leaf architecture, where leaves are oriented more vertically, is desirable for optimizing light distribution and reducing heat load in high-radiation environments. This arrangement allows light to penetrate deeper into the canopy, improving the photosynthetic efficiency of lower leaves while minimizing the direct exposure of upper leaves. Combined with deep roots, this architecture significantly enhances the plant's overall resilience.

229. (B) Forming a physical film to reduce water loss.
The application of chemical anti-transpirants to foliage during a drought serves to modify the plant's water status by forming a physical film or inducing stomatal closure to reduce water loss. By limiting transpiration, these substances help the plant conserve its internal moisture during acute stress periods. This can be a valuable short-term management tool for protecting crops from dehydration.

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230. (C) Deep root architecture, stay-green capability, high intrinsic water use efficiency, and early morning anthesis to avoid peak daily temperatures
A highly climate-resilient wheat variety would ideally possess a deep root system, the "stay-green" capability, high intrinsic water use efficiency, and early morning anthesis. These combined traits allow the plant to access deep water, maintain photosynthesis longer, use moisture effectively, and avoid peak temperatures that cause reproductive damage. Developing such varieties is a primary goal of modern crop science.

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in sediments, increased bioavailability in acidic soils, and limited translocation of lead from roots to shoots are accurate scientific descriptions.

214. (C) Arsenic (As)
Arsenic is a toxic metalloid that accumulates significantly in rice grains grown in contaminated, flooded soils. This occurs because arsenic is chemically similar to silicic acid and is taken up by the same transport pathways. As rice is a staple food for billions of people, the accumulation of arsenic in the harvest is a major public health concern globally.

215. (D) Reduced arsenite is readily taken up via aquaporins.
Flooding exacerbates arsenic uptake in rice because the anaerobic conditions in the soil convert arsenic from its less mobile arsenate form to the more soluble and toxic arsenite form. This arsenite is then readily taken up by the rice roots via aquaporins. Understanding this geochemical process is essential for developing agricultural management strategies, such as intermittent irrigation, to reduce arsenic.

216. (A) Competitively inhibit the uptake of essential Iron.
The chlorosis observed in plants under heavy metal stress is frequently caused by the competitive inhibition of iron uptake. Metals like cadmium and zinc can substitute for iron in various biochemical processes or block its transport into the plant. Since iron is essential for chlorophyll synthesis, its deficiency leads to leaf yellowing, which is a classic symptom of toxicity.

217. (B) Stay-green trait
Agronomic adaptation to terminal heat stress in wheat often relies on breeding for the "stay-green" trait. This characteristic allows the plant's leaves to remain photosynthetically active for a longer period during the grain-filling stage, even under high temperatures. By extending the duration of carbon assimilation, stay-green varieties can maintain higher grain weights and yields despite stress, improving crop resilience.

218. (B) Altering the sowing date (e.g., early planting) to ensure critical reproductive stages avoid peak mid-summer heat or terminal drought
Shifting crop phenology as an adaptation strategy involves altering the sowing date to ensure that critical reproductive stages do not coincide with periods of peak summer heat or terminal drought. By planting earlier or using faster-maturing varieties, farmers can avoid the most stressful conditions of the growing season. This simple management change is a key component of climate-smart agriculture.

219. (A) Utilizing overhead sprinkler irrigation to release latent heat of fusion as the water freezes on the buds
Overhead sprinkler irrigation is an effective technique for protecting orchard crops from unseasonal spring frosts. As the water freezes on the buds and branches, it releases the latent heat of fusion, which helps maintain the temperature of the plant tissues at or near freezing. This prevents the delicate reproductive structures from suffering lethal damage, ensuring a successful fruit harvest.

220. (A) Both A and R are true and R is the correct explanation of A.
Developing crop varieties with deeper root architectures is a critical strategy for drought resilience. These roots allow the plant to access moisture stored in the subsoil, which remains stable even when the topsoil has dried out. Both the assertion that this is a vital genetic goal and the reason describing its hydrological benefit are correct for plant health.

221. (D) Buffering temperature and reducing moisture loss.
Conservation agriculture practices, such as zero-tillage and residue retention, modify the soil microclimate by buffering temperatures and reducing moisture loss. The layer of crop residue acts as a physical barrier that slows evaporation and insulates the soil from extreme heat. These benefits are essential for maintaining soil health and crop productivity under the increasingly variable weather conditions associated with climate.

222. (C) Genotype capacity to produce adaptive phenotypes.
Phenotypic plasticity is the capacity of a single genotype to produce different adaptive phenotypes in response to varying environmental conditions. In the context of climate resilience, high plasticity allows a crop to adjust its growth, physiology, or development to survive well under a range of stressors. Breeding for this trait is

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187. (A) Sulfur dioxide (SO_2) and Nitrogen oxides (NO_x)
Acid rain is primarily caused by the atmospheric oxidation and hydrolysis of sulfur dioxide and nitrogen oxides. These pollutants, released from fossil fuel combustion and industrial processes, react with water vapor to form sulfuric and nitric acids. When this acidic precipitation falls to the Earth, it can lower the pH of soils and water bodies, leading to significant environmental damage to ecosystems.

188. (C) Heavy leaching of basic cations (Ca^{2+}, Mg^{2+}) and mobilization of toxic aluminum (Al^{3+}) in the soil
A major indirect consequence of chronic acid rain on forest ecosystems is the leaching of essential basic cations like calcium and magnesium from the soil. Additionally, the increased acidity can mobilize toxic aluminum ions, which damage plant roots and impair their ability to take up water and nutrients. These changes in soil chemistry can lead to widespread forest decline and reduced biodiversity.

189. (D) By oxidizing it to less toxic sulfate via enzymes.
Plants attempt to detoxify sublethal levels of internalized sulfite by oxidizing it to less toxic sulfate using specific enzymes. Once converted to sulfate, the sulfur can be safely sequestered in the vacuole or incorporated into essential sulfur-containing amino acids and proteins. This metabolic pathway is a vital defense mechanism that allows plants to tolerate low-level sulfur dioxide pollution without severe damage.

190. (A) I and II
Scientific evidence shows that nitrogen dioxide is significantly more phytotoxic than nitric oxide. Interestingly, at extremely low concentrations, the uptake of NO_x can inadvertently serve as a supplemental nitrogen source for the plant. However, high acute doses do not primarily cause root necrosis; instead, they damage the foliage. Therefore, only the first two statements accurately describe the effects of NO_x.

191. (B) Stomata may remain abnormally open, leading to severe desiccation under drought conditions.
Exposure to moderate levels of sulfur dioxide can cause a paradoxical response where stomata remain abnormally open. This failure to close can lead to severe desiccation, especially if the plant is also experiencing drought conditions. By disrupting the normal regulation of the guard cells, SO_2 compromises the plant's ability to manage its water balance, making it more vulnerable to multiple stressors.

192. (D) The chloroplast
The chloroplast is the primary site of damage when heavy bisulfite accumulation disrupts electron transport and photophosphorylation. These toxic sulfur compounds interfere with the light-harvesting machinery and the enzymes of the Calvin cycle, severely reducing the plant's capacity for photosynthesis. Because the chloroplast is so central to plant life, its damage is a major factor in the health decline observed.

193. (A) Nitrogen oxides (NO_x) and Volatile Organic Compounds (VOCs)
Photochemical smog is characterized by secondary pollutants like ozone and PAN, which are generated by the action of sunlight on nitrogen oxides and volatile organic compounds. These precursor pollutants, often from vehicle emissions and industrial sources, react in the presence of UV radiation to form a complex mixture of toxic gases. This type of smog is a major urban environmental problem.

194. (C) Generating ROS that degrade cellular membranes.
Tropospheric ozone causes damage primarily by generating reactive oxygen species within the leaf tissue. Once ozone enters through the stomata, it reacts with components of the cell wall and plasma membrane, producing highly reactive molecules like hydroxyl radicals. These ROS then degrade cellular membranes and proteins, leading to oxidative stress, impaired photosynthesis, and visible symptoms of injury on the leaf.

195. (A) Upper-surface "flecking" or "stippling" (small pigmented or necrotic spots) usually between the veins
The classic diagnostic indicator of acute ozone injury in broad-leaved crops is upper-surface flecking or stippling. These are small, pigmented or necrotic spots that appear between the veins of the leaf. This specific symptom pattern results from the localized death of mesophyll cells in response to ozone-induced oxidative

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CHAPTER 08
Seed Physiology

2019

1. Which of the following best defines an exalbuminous seed?
(A) A seed that retains a large volume of endosperm at maturity for reserve storage
(B) A seed that stores its nutritional reserves exclusively in the maternal perisperm
(C) A seed lacking cotyledons entirely during its early developmental phases
(D) A seed where the endosperm is consumed by the developing embryo before maturity

2004

2. During seed embryogenesis, which developmental stage immediately follows the globular stage in dicotyledons?
(A) Mature stage
(B) Torpedo stage
(C) Heart stage
(D) Proembryo stage

2010

3. Which pathway is predominantly responsible for phloem unloading of assimilates into the developing endosperm of cereal grains?
(A) Strictly symplastic unloading directly into the interior cells of the endosperm
(B) Apoplastic unloading from maternal tissues before uptake by the endosperm
(C) Direct vascular connections linking the primary phloem to the aleurone layer
(D) Xylem-mediated transfer of assimilates driven primarily by transpiration pull

2018

4. Based on Osborne's classification, which seed storage proteins are highly soluble in aqueous alcohol?
(A) Glutelins
(B) Globulins
(C) Albumins
(D) Prolamins

2002

5. Which integral membrane proteins are primarily responsible for stabilizing the phospholipid half-unit membrane of seed oil bodies?
(A) Oleosins
(B) Aquaporins
(C) Globulins
(D) Expansins

2017

6. During which phase of seed maturation does the maximum accumulation of storage reserves typically occur?
(A) Histodifferentiation phase
(B) Maturation drying phase
(C) Cell expansion phase
(D) Post-abscission phase

2015

7. What characterizes an intermediate seed in terms of desiccation tolerance?
(A) It can tolerate partial desiccation but is injured by freezing temperatures at low moisture
(B) It can survive desiccation to extremely low moisture contents of 2-5% without injury
(C) It loses viability rapidly if moisture content falls below a critical level of 40%
(D) It germinates viviparously on the mother plant without any desiccation phase

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2002

8. What is the primary physiological function of Late Embryogenesis Abundant (LEA) proteins during seed maturation?
(A) They act as specialized lipases to efficiently break down stored lipid reserves
(B) They catalyze the enzymatic synthesis of various protective non-reducing sugars
(C) They trigger the immediate onset of rapid germination upon initial rehydration
(D) They protect cellular structures and proteins from desiccation-induced damage

2024

9. In the Tetrazolium (TZ) test for seed viability, living tissues stain red due to the activity of which enzyme system?
(A) Peroxidases
(B) Dehydrogenases
(C) Amylases
(D) Lipases

2007

10. During the triphasic curve of seed water imbibition, what represents Phase II?
(A) Rapid initial water uptake driven primarily by the matric potential of the seed
(B) Radicle emergence and resumption of rapid water uptake
(C) A lag phase with minimal water uptake but high metabolic activity
(D) The total cessation of all internal respiratory and metabolic activity

2005

11. Which process represents the earliest respiratory event upon seed imbibition before mitochondrial biogenesis occurs?
(A) De novo synthesis of the full suite of Tricarboxylic Acid (TCA) cycle enzymes
(B) Immediate reliance on anaerobic fermentation until the radicle emerges through the coat
(C) Photophosphorylation within the embryonic axis using light that penetrates the testa
(D) Reactivation of pre-existing glycolysis and oxidative pentose phosphate pathway enzymes

2018

12. Consider the following statements regarding lipid mobilization in seeds:
I. Beta-oxidation of fatty acids occurs exclusively in the mitochondria of germinating seeds.
II. The glyoxylate cycle converts acetyl-CoA to succinate in the glyoxysomes.
III. Succinate is transported to the mitochondria to enter the TCA cycle.
Which of the above statements are correct?
(A) I and II
(B) II and III
(C) I
(D) III

2010

13. Which enzyme is responsible for cleaving the α -1,6-glycosidic branch points during the complete hydrolysis of amylopectin in germinating seeds?
(A) α-amylase
(B) Limit dextrinase
(C) β-amylase
(D) α-glucosidase

2023

14. What is the distinguishing action of exopeptidases during protein breakdown in germinating seeds?
(A) They cleave internal peptide bonds of large storage proteins
(B) They remove amino acids sequentially from the terminal ends of peptide chains
(C) They selectively degrade only the prolamin fraction found within the endosperm
(D) They convert free amino acids into specific amides for subsequent transport

2023

15. In what primary chemical form are mobilized carbohydrate reserves transported from the endosperm to the growing embryonic axis?
(A) Sucrose
(B) Starch
(C) Glucose
(D) Fructose

2002

16. Which structure acts the primary secretory tissue for hydrolytic enzymes into the starchy endosperm of cereal grains?
(A) Scutellum
(B) Coleoptile
(C) Aleurone layer
(D) Coleorhiza

2006

17. In the gibberellin signaling pathway within seeds, what is the specific role of the GA-MYB transcription factor?
(A) It acts as a repressor for the synthesis of various hydrolytic enzymes
(B) It facilitates the degradation of DELLA proteins via the ubiquitination pathway
(C) It catalyzes the synthesis of gibberellic acid within the aleurone layer cells
(D) It binds to the promoter of the α-amylase gene to induce its transcription

2022

18. Read the following statements and select the correct option.
Assertion (A): Hard seed coats containing a dense layer of macrosclereid cells impose physical dormancy.
Reason (R): Macrosclereid cells synthesize germination inhibitors that diffuse into the embryo.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

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2017

19. What is the most appropriate definition of secondary seed dormancy?
(A) Dormancy that is induced during the stages of seed development on the mother plant
(B) Dormancy induced in mature, non-dormant seeds by unfavorable environmental conditions
(C) Dormancy caused strictly by the presence of an underdeveloped embryonic axis at dispersal
(D) Dormancy that can only be overcome by applying intense mechanical scarification to the coat

2012

20. Which statement INCORRECTLY describes the hormonal antagonism in seeds?
(A) High ABA levels promote the maintenance of seed dormancy
(B) An increased GA to ABA ratio triggers germination
(C) ABA application suppresses the expression of α-amylase genes
(D) Gibberellins induce dormancy by activating LEA protein synthesis

2019

21. Which artificial method is specifically designed to overcome morphological dormancy involving an underdeveloped embryo?
(A) Warm or cold stratification to allow embryo growth
(B) Mechanical scarification of the seed coat using industrial sandpaper
(C) Immersion of the seeds in a solution of concentrated sulfuric acid
(D) Treatment of the seeds with boiling water to crack the hard outer layer

2014

22. What physiological process occurs during the after-ripening of dry dormant seeds?
(A) Accumulation of massive amounts of storage starch within the embryonic tissue
(B) Complete and permanent cessation of all metabolic reactions within the seed
(C) A shift in transcriptomic profiles and a decrease in sensitivity to ABA
(D) The immediate emergence of the primary radicle through the protective seed coat

2010

23. Which of the following correctly pairs the seed type with its characteristic?
(A) Monocot seed - Typically possesses a large scutellum
(B) Albuminous seed - Stores food predominantly in the cotyledons
(C) Exalbuminous seed - Retains a persistent endosperm
(D) Dicot seed - Always lacks an aleurone layer

2008

24. Which developmental event marks the transition from the heart stage to the torpedo stage in dicot embryogenesis?
(A) Initial division of the zygote to form the apical and basal cells
(B) Formation of the suspensor that anchors the embryo to maternal tissue
(C) Complete and severe desiccation of the embryo before maturation drying
(D) Elongation of the cotyledons and the primary embryonic axis

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2003

25. Consider the following statements regarding source-sink dynamics in grains:
I. The maternal phloem symplastically unloads directly into the endosperm of dicots.
II. A post-phloem apoplastic step is obligatory for assimilate transfer to the embryo.
III. Sucrose transporters are essential for taking up sugars from the apoplast.
IV. The chalazal region plays a key role in assimilate entry in many seeds.
Which of the above statements are INCORRECT?
(A) I
(B) II and IV
(C) I, III and IV
(D) II, III and IV

2016

26. Which class of storage proteins constitutes the major fraction in wheat (Triticum aestivum) grains?
(A) Albumins and Globulins
(B) Prolamins and Albumins
(C) Prolamins and Glutelins
(D) Globulins and Glutelins

2005

27. Where is starch primarily synthesized and stored at the cellular level during seed development?
(A) Oleosomes
(B) Protein bodies
(C) Mitochondria
(D) Amyloplasts

2008

48. Select the correct sequence of seed maturation phases:
(A) Histodifferentiation → Reserve accumulation → Maturation drying
(B) Maturation drying → Reserve accumulation → Histodifferentiation
(C) Reserve accumulation → Histodifferentiation → Maturation drying
(D) Histodifferentiation → Maturation drying → Reserve accumulation

2022

49. Which microscopic feature is uniquely associated with the ultrastructure of starch granules in seeds?
(A) They are surrounded by a phospholipid bilayer embedded with oleosins
(B) They are purely composed of unbranched amylopectin
(C) They possess a double-layered cell wall composed of cellulose
(D) They contain alternating amorphous and crystalline lamellae

2017

50. What is a defining physiological trait of orthodox seeds?
(A) They initiate germination while still attached to the mother plant
(B) They exhibit a complete lack of primary dormancy
(C) They acquire the ability to tolerate severe water loss before shedding
(D) They maintain a moisture content above 50% throughout their lifespan

2008

51. Heat shock proteins (HSPs) are critical during seed desiccation because they:
(A) Provide the main energy source for germination
(B) Act as molecular chaperones preventing protein aggregation
(C) Induce the synthesis of amylases within the aleurone layer
(D) Break down cell walls to facilitate rapid radicle emergence

2019

52. Which structural change is a direct consequence of lipid peroxidation in aging seeds?
(A) Significant thickening of the aleurone layer within the seed
(B) Enhanced cross-linking of starch granules in the endosperm
(C) Immediate breaking of physiological dormancy within the embryo
(D) Loss of cellular membrane integrity and increased solute leakage

2009

53. Which of the following is NOT a phase of the seed hydration triphasic curve?
(A) Plasmolysis phase
(B) Rapid initial imbibition
(C) Lag phase
(D) Radicle emergence phase

2004

54. The transition from glycolysis to the TCA cycle during seed germination is heavily dependent on:
(A) The complete exhaustion of all internal starch reserves
(B) The transition to an entirely anaerobic environment
(C) The biogenesis and structural repair of mitochondria
(D) The accumulation of various organic acids like lactic acid

2013

55. Consider the following statements regarding the glyoxylate cycle:
I. It requires the enzymes isocitrate lyase and malate synthase.
II. It effectively bypasses the decarboxylation steps of the TCA cycle.
III. It results in the net loss of carbon as CO_2.
Which of the above statements are correct?
(A) I and III
(B) I and II
(C) II and III
(D) I

2001

56. What distinguishes the action of β-amylase from α-amylase in seed carbohydrate metabolism?
(A) β-amylase attacks α-1,6 linkages, while α -amylase attacks internal α-1,4 linkages
(B) β-amylase functions only in the mitochondria, while α-amylase is strictly cytosolic
(C) β-amylase is solely synthesized de novo, while α-amylase is entirely pre-existing
(D) β-amylase produces maltose from the non-reducing ends, while α-amylase acts internally

2015

57. Which amino acid is widely recognized as a major transport compound for mobilized nitrogen in germinating legumes?

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(B) Site of primary lipid storage for the developing seedling
(C) Specialized absorptive organ for mobilized nutrients
(D) Region of deep dormancy enforcement through chemical inhibitors

2012

39. Which repressor protein is degraded following gibberellin perception, thereby allowing GA-responsive gene transcription in seeds?
(A) DELLA
(B) AUX/IAA
(C) JAZ
(D) EIN3

2004

40. A seed that fails to germinate because the radicle cannot physically penetrate the surrounding endosperm is exhibiting which type of dormancy?
(A) Physical dormancy
(B) Morphological dormancy
(C) Combinational dormancy
(D) Physiological dormancy

2021

41. Which phenomenon explains why seeds developed under cool, damp conditions often exhibit stronger primary dormancy than those developed under hot, dry conditions?
(A) After-ripening
(B) Maternal environmental effect
(C) Secondary dormancy induction
(D) Vivipary

2006

42. How does the application of exogenous KNO3 typically influence seed germination?
(A) It drastically lowers the water potential, preventing imbibition
(B) It irreversibly binds to endogenous GA receptors to prevent signal transduction
(C) It acts as a signaling molecule to break dormancy and stimulate germination
(D) It cross-links various structural proteins in the seed coat to harden the tissue

2023

43. Which environmental condition is most critical for the process of after-ripening to successfully alleviate seed dormancy?
(A) Continuous complete submersion of the seed in oxygen-depleted water
(B) Exposure to freezing temperatures in a fully hydrated state
(C) Absolute darkness with zero oxygen availability
(D) Storage in a dry state at room or slightly elevated temperatures

2021

44. What characterizes the mature embryo of a typical monocotyledonous seed?
(A) A single modified cotyledon called the scutellum
(B) The presence of two well-developed cotyledons
(C) A highly developed taproot system enclosed in the pericarp
(D) The complete absence of a radicle meristem

2014

45. Consider the following statements regarding embryogenesis:
I. The globular stage involves rapid cell division and spherical symmetry.
II. The heart stage marks the initiation of bilateral symmetry in dicots.
III. The suspensor anchors the embryo and transfers nutrients.
IV. The torpedo stage occurs prior to the heart stage.
V. Mature embryos generally undergo a desiccation phase.
Which of the above statements are correct?
(A) I, II, III and V
(B) II, III, IV and V
(C) I, III and IV
(D) I, II and IV

NODIA

2017

46. What specific role does the chalazal pad play in the development of dicotyledonous seeds?
(A) It synthesizes the hard seed coat to provide mechanical protection
(B) It serves as the primary site of phloem unloading from maternal tissue
(C) It directly differentiates into the radicle meristem during early growth
(D) It absorbs water during the initial triphasic curve of seed hydration

2010

47. Based on their solubility in dilute saline solutions, which proteins are primarily extracted?
(A) Globulins
(B) Albumins
(C) Prolamins
(D) Glutelins

(B) Cytokinin
(C) Abscisic Acid (ABA)
(D) Ethylene

2011

87. What is the fundamental outcome of applying thiourea to certain dormant seeds?
(A) It promotes germination by overcoming specific physiological blocks
(B) It permanently hardens the seed coat
(C) It forces the seed into deep secondary dormancy
(D) It exclusively degrades starch reserves

2009

88. How does the transcriptome of a dry seed change during after-ripening?
(A) It remains completely static due to the lack of free water
(B) All DNA is degraded and subsequently resynthesized upon hydration
(C) Only genes associated with the process of photosynthesis are expressed
(D) Specific targeted mRNA transcripts are selectively degraded or synthesized via subtle hydration pockets

2015

89. Which anatomical feature fundamentally differentiates a typical dicot seed from a typical monocot seed?
(A) The presence of a functional embryo within the seed
(B) The presence of two cotyledons versus one
(C) The presence of a protective seed coat surrounding the tissues
(D) The fundamental reliance on water for the initiation of germination

2025

90. Which of the following describes the behavior of a zygote during early embryogenesis?
(A) It immediately matures into a desiccation-tolerant state
(B) It forms the specialized aleurone layer directly from its first division
(C) It undergoes unequal transverse division to form an apical and a basal cell
(D) It rapidly synthesizes massive amounts of starch before dividing

2001

91. The pathway of assimilate transfer in developing seeds often utilizes specialized cells with cell wall ingrowths to increase surface area. What are these cells called?
(A) Guard cells
(B) Companion cells
(C) Sieve tube elements
(D) Transfer cells

2006

92. In Osborne's protein classification, which fraction is soluble in dilute acids or alkalis?
(A) Glutelins
(B) Albumins
(C) Globulins
(D) Prolamins

2010

93. What limits the coalescence of oleosomes (oil bodies) during seed desiccation?
(A) The rigid crystalline structure of triglycerides
(B) The physical barrier created by oleosin proteins on their surface
(C) The presence of starch-storing amyloplasts dispersed between them
(D) The maintenance of a high concentration of internal cellular water

2021

94. The transition from the reserve accumulation phase to the maturation drying phase is primarily orchestrated by which plant hormone?
(A) Gibberellic acid
(B) Abscisic acid (ABA)
(C) Auxin
(D) Salicylic acid

2019

95. Intermediate seeds share characteristics of both orthodox and recalcitrant seeds. Which is a hallmark of intermediate seeds?
(A) They can be dried to 10-12% moisture but are sensitive to freezing at low moisture
(B) They can be dried to 2-5% moisture and stored at -20°C
(C) They lose viability if dried below 30-40% moisture
(D) They only germinate while attached to the mother plant (vivipary)

2019

96. Which biophysical state is achieved in orthodox seeds due to the high concentration of non-reducing sugars during severe desiccation?
(A) Liquid crystalline state
(B) Supercooled aqueous state
(C) Glassy (vitreous) state
(D) Gaseous state

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(A) Tryptophan
(B) Asparagine
(C) Methionine
(D) Cysteine

2023

58. By what mechanism are mobilized breakdown products prevented from accumulating to inhibitory levels in the endosperm?
(A) They are rapidly converted into various toxic alkaloids for defense
(B) They are degraded into gaseous nitrogen and carbon dioxide by-products
(C) They are continuously translocated to and utilized by the strong sink of the growing embryo
(D) They are sequestered permanently inside specialized storage vacuoles

2019

59. Which physical structure in the cereal grain is responsible for separating the starchy endosperm from the embryo?
(A) Testa
(B) Coleoptile
(C) Pericarp
(D) Scutellar epithelium

2007

60. How does the aleurone layer respond to gibberellic acid (GA) originating from the embryo?
(A) It synthesizes and secretes hydrolytic enzymes such as α-amylase
(B) It undergoes programmed cell death immediately to provide nutrients
(C) It accumulates abscisic acid to halt any further germination processes
(D) It differentiates into a secondary root system to aid in nutrient uptake

2017

61. Which type of dormancy is explicitly caused by the presence of a hard, water-impermeable seed coat?
(A) Morphological dormancy
(B) Physical dormancy
(C) Physiological dormancy
(D) Embryo dormancy

2006

62. Read the following statements and select the correct option.
Assertion (A): Secondary dormancy is an adaptive trait that prevents germination under temporarily unfavorable conditions.
Reason (R): Secondary dormancy can only occur in seeds that never possessed primary dormancy.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2006

63. Which condition typically favors the maintenance of seed dormancy by upregulating ABA biosynthesis?
(A) High temperature stress during imbibition (thermo-dormancy)
(B) Exposure to red light in photoblastic seeds
(C) Prolonged exposure to cold stratification in a fully hydrated state
(D) Treatment with exogenous GA3 to promote early radical emergence

NODIA

2005

64. What is the primary purpose of chemical scarification with concentrated sulfuric acid?
(A) To provide essential sulfur nutrients to the embryo
(B) To act as a direct substitute for gibberellic acid
(C) To soften or erode a hard, impermeable seed coat
(D) To increase the intracellular pH of the seed

2006

65. The process of dry after-ripening in seeds is most accurately described as:
(A) A rapid increase in seed moisture content leading to immediate germination
(B) The artificial removal of the seed coat using various abrasive industrial materials
(C) The infection of the seed by beneficial fungi to chemically break the dormancy phase
(D) A time-dependent loss of dormancy during dry storage accompanied by biochemical shifts

2025

66. In an albuminous seed, what is the primary role of the cotyledons during early germination?
(A) To serve as the sole massive storage organ for the seed
(B) To emerge immediately and begin photosynthesis before radicle emergence
(C) To act as haustorial organs that absorb nutrients from the endosperm
(D) To physically break the seed coat through rapid swelling

2025

28. Which physiological parameter sharply decreases during the final maturation drying phase of seed development?
(A) Water potential
(B) Dry weight
(C) ABA concentration
(D) Soluble protein content

2023

29. Recalcitrant seeds are most commonly found in which type of ecological environment?
(A) Arid deserts
(B) Tropical rainforests
(C) Temperate grasslands
(D) Alpine tundras

2025

30. How do non-reducing sugars like trehalose protect cellular structures during seed desiccation?
(A) By significantly increasing the average kinetic energy of internal water molecules
(B) By replacing water molecules and hydrogen-bonding to membrane phospholipids
(C) By catalyzing the rapid breakdown of misfolded or aggregated cellular proteins
(D) By lowering the intracellular pH to stabilize various metabolic enzymes

2011

31. Which biochemical event is a primary cause of seed deterioration and loss of viability during prolonged storage?
(A) Lipid peroxidation by reactive oxygen species
(B) Accumulation of Late Embryogenesis Abundant (LEA) proteins during maturation
(C) Synthesis of heat shock proteins in response to elevated environmental temperatures
(D) Enhanced production of various gibberellins within the germinating embryonic axis

2007

32. What is the principal driving force for water uptake during Phase I (imbibition) of seed hydration?
(A) Solute potential
(B) Pressure potential
(C) Matric potential
(D) Gravitational potential

2019

33. Match the metabolic event (List-I) with its corresponding phase of seed germination (List-II).
List I: (Metabolic Event)
P. Reactivation of pre-existing enzymes
Q. Major mitochondrial biogenesis
R. Emergence of the radicle
S. Rapid initial water uptake
List II: (Phase)
1. Phase III
2. Phase II
3. Phase I
4. Transition from Phase I to II
(A) P-4, Q-2, R-1, S-3
(B) P-3, Q-2, R-1, S-4
(C) P-4, Q-3, R-1, S-2
(D) P-2, Q-1, R-4, S-3

2004

34. Which organelle works in conjunction with glyoxysomes and mitochondria to convert stored lipids into sucrose?
(A) Chloroplast
(B) Golgi apparatus
(C) Cytosol
(D) Vacuole

2005

35. What is the physiological consequence of α -glucosidase activity during carbohydrate breakdown in seeds?
(A) Cleavage of intact starch grains into large limit dextrins
(B) Hydrolysis of maltose into free glucose molecules
(C) Debranching of amylopectin molecules
(D) Synthesis of sucrose for transport

2011

36. Which class of enzymes initiates the degradation of insoluble storage proteins into smaller soluble peptides in seeds?
(A) Carboxypeptidases
(B) Aminopeptidases
(C) Dipeptidases
(D) Endopeptidases

2004

37. Amides such as glutamine and asparagine are primarily transported to the growing embryonic axis to supply which essential nutrient?
(A) Nitrogen
(B) Phosphorus
(C) Potassium
(D) Calcium

2009

38. In the cereal grain, the scutellum functions primarily as a:
(A) Protective barrier against pathogen entry

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(D) Degradation of the entire embryonic axis due to lack of water

2025

77. Which metabolic pathway yields the majority of ATP for the growing embryo once the radicle has emerged and oxygen is fully available?
(A) Reliance on anaerobic glycolysis in the absence of light
(B) Oxidative phosphorylation linked to the TCA cycle
(C) Photophosphorylation within the newly emerged green tissues
(D) The oxidative pentose phosphate pathway

2002

78. Consider the following statements regarding enzyme activities in seeds:
I. Lipases cleave fatty acids from glycerol.
II. Isocitrate lyase is a key enzyme of glycolysis.
III. Limit dextrinase debranches starches.
IV. Exopeptidases release single amino acids.
Which of the above statements are correct?
(A) I and II
(B) II
(C) I, III and IV
(D) III and IV

2002

79. The synergistic action of amylases in the endosperm results primarily in the accumulation of which disaccharide?
(A) Maltose
(B) Sucrose
(C) Lactose
(D) Cellobiose

2003

80. By what mechanism do endopeptidases facilitate protein mobilization?
(A) Cleaving peptide bonds exclusively at the C-terminus
(B) Cleaving peptide bonds exclusively at the N-terminus
(C) Hydrolyzing internal peptide bonds to produce oligopeptides
(D) Converting free amino acids directly into amides for long-distance transport

2002

81. Ureides (such as allantoin) serve primarily as transport molecules for which element in some legume seeds?
(A) Carbon
(B) Phosphorus
(C) Sulfur
(D) Nitrogen

2004

82. Which tissue in the dicot seed is structurally analogous in function to the scutellum of monocots regarding reserve absorption?
(A) The radicle
(B) The seed coat
(C) The cotyledons
(D) The hypocotyl

2003

83. De novo synthesis of α-amylase in the aleurone layer is dependent on the prior synthesis of which specific messenger molecule induced by GA?
(A) ABA
(B) GA-MYB mRNA
(C) Ethylene
(D) DELLA protein

2012

84. A seed requires a period of cold, moist conditions to overcome dormancy. This indicates the seed possesses:
(A) Physical dormancy
(B) Morphological dormancy
(C) Recalcitrant behavior
(D) Physiological dormancy

2025

85. Match the seed dormancy treatment (List-I) with its underlying mechanism (List-II).
List I: (Dormancy Treatment)
P. Mechanical scarification
Q. Cold stratification
R. Thiourea application
S. Exogenous GA3
List II: (Mechanism)
1. Substitutes for endogenous gibberellin synthesis
2. Physically breaches the impermeable seed coat
3. Stimulates the pentose phosphate pathway/ overcomes inhibition
4. Satisfies chilling requirement to alter ABA/ GA ratio
(A) P-2, Q-4, R-3, S-1
(B) P-4, Q-2, R-1, S-3
(C) P-2, Q-3, R-4, S-1
(D) P-3, Q-1, R-2, S-4

2025

86. Which hormone is recognized as the primary antagonist to gibberellin in the regulation of seed germination?
(A) Auxin

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2022

67. Which of the following structures is uniquely identifiable during the torpedo stage of embryogenesis?
(A) A perfectly spherical mass consisting of undifferentiated cells only
(B) Distinctly elongated cotyledons and a well-defined embryonic axis
(C) A massive persistent suspensor that outgrows the embryo
(D) A fully degraded and absorbed seed coat that exposes the embryo

2006

68. What role do invertases play in source-sink dynamics during seed filling?
(A) They synthesize complex starch molecules directly from sucrose
(B) They transport intact sucrose molecules across the apoplastic space
(C) They effectively inhibit the unloading of various phloem elements
(D) They convert incoming sucrose into glucose and fructose to maintain a concentration gradient

2016

69. Which chemical component represents the major energy storage form in oilseed crops like Brassica?
(A) Triacylglycerols
(B) Starch
(C) Globulins
(D) Sucrose

2006

70. Where is protein bodies typically formed during seed maturation?
(A) Smooth endoplasmic reticulum membranes
(B) The interior of the nucleus
(C) Rough endoplasmic reticulum and vacuoles
(D) The matrix of the mitochondria

2012

71. The histodifferentiation phase of seed development is primarily characterized by:
(A) Rapid cell division and formation of the basic embryonic body plan
(B) Maximum dry weight accumulation
(C) Severe desiccation and loss of water
(D) The massive synthesis of Late Embryogenesis Abundant proteins

2022

72. Arrange the following steps of lipid mobilization in the correct sequence:
I. Conversion of succinate to malate and then oxaloacetate
II. Hydrolysis of triacylglycerols by lipase
III. Conversion of oxaloacetate to sucrose via gluconeogenesis
IV. Beta-oxidation of fatty acids to acetyl-CoA
(A) II, IV, I, III
(B) II, I, IV, III
(C) IV, II, I, III
(D) I, III, II, IV

2024

73. Why are recalcitrant seeds highly susceptible to chilling injury?
(A) They possess excessive amounts of Late Embryogenesis Abundant (LEA) proteins
(B) They lack desiccation tolerance and maintain high moisture, leading to membrane phase transitions
(C) They have an excessively thick seed coat that traps and holds cold air
(D) They rapidly accumulate toxic levels of sucrose when stored at low temperatures

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2019

74. Which specific carbohydrate is a well-known non-reducing sugar crucial for glassy state formation during seed desiccation?
(A) Glucose
(B) Fructose
(C) Sucrose
(D) Galactose

2015

75. The physiological aging of seeds is commonly associated with an increase in:
(A) The synthesis of intact and functional Late Embryogenesis Abundant proteins
(B) The percentage of successful and uniform germination in a seed lot
(C) Total starch content within the starchy endosperm of the seed
(D) Reactive Oxygen Species (ROS) accumulation and oxidative stress

2025

76. During Phase II (the lag phase) of seed imbibition, which internal process is highly active despite minimal water uptake?
(A) Mobilization of reserves and transcriptomic activation
(B) Rapid desiccation of the internal tissues following initial imbibition
(C) Synthesis of new LEA proteins to prevent hydration

2015

97. The loss of seed viability over time is mathematically modeled using which established set of equations?
(A) Michaelis-Menten enzyme kinetics equations
(B) Hardy-Weinberg genetic equilibrium equations
(C) Nernst electrical potential equations
(D) Ellis and Roberts viability equations

2015

98. Consider the following statements regarding seed hydration:
I. Phase I is characterized by physical water imbibition.
II. Phase II involves metabolic preparation but low water uptake.
III. Phase III occurs only in dead seeds.
IV. Radicle emergence generally marks the start of Phase III.
V. Matric potential drives Phase I.
Which of the above statements are correct?
(A) I, II, IV and V
(B) I, II, III and V
(C) II, III and IV
(D) I, III, IV and V

2007

99. The resumption of respiration during early Phase I of germination relies primarily on:
(A) De novo synthesized mitochondria produced during early imbibition
(B) Pre-existing mitochondria that undergo structural repair
(C) Chloroplasts that begin functioning immediately even in the dark
(D) Anaerobic methanogenesis occurring within the hydrated embryo

2015

100. During the glyoxylate cycle, which enzyme catalyzes the cleavage of isocitrate into glyoxylate and succinate?
(A) Malate synthase
(B) Citrate synthase
(C) Aconitase
(D) Isocitrate lyase

2025

101. Which component of starch is a highly branched polymer composed of α-1,4 and α-1,6 glycosidic bonds?
(A) Amylopectin
(B) Amylose
(C) Cellulose
(D) Lignin

2013

102. What is the ultimate fate of the free amino acids generated by the action of peptidases in the endosperm?
(A) They are permanently stored in the aleurone layer
(B) They are translocated to the embryonic axis for new protein synthesis
(C) They are excreted from the seed as waste
(D) They are converted back into insoluble storage proteins within the endosperm

2007

103. Which transport mechanism primarily facilitates the movement of sucrose from the scutellum into the developing embryonic axis?
(A) Simple diffusion across the lipid bilayer
(B) Bulk flow through the newly formed xylem vessels
(C) Endocytosis of large sugar molecules into the cells
(D) Active transport mediated by sucrose-H^+ symporters

2024

104. In barley seeds, the synthesis of which hydrolytic enzyme is the classic physiological marker for GA response in the aleurone layer?
(A) β-galactosidase
(B) Lipoxygenase
(C) Catalase
(D) α-amylase

2002

105. Read the following statements and select the correct option.
Assertion (A): Gibberellic acid (GA) triggers the mobilization of endosperm reserves in cereal grains.
Reason (R): GA diffuses from the embryo to the aleurone layer, where it induces the transcription of genes encoding hydrolytic enzymes.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2012

106. Which morphological feature characterizes seeds exhibiting morphological dormancy?
(A) A massive, fully mature embryo that lacks metabolic activity
(B) An embryo that is undifferentiated or rudimentary at the time of seed dispersal

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2025

167. Which specific limit dextrin-hydrolyzing enzyme is crucial for the complete saccharification of starch but is often the rate-limiting step in industrial malting?
(A) α-amylase
(B) β-amylase
(C) Hexokinase
(D) Limit dextrinase (pullulanase)

2021

168. Protein body degradation during germination is often initiated by a drop in internal pH. This acidic environment optimizes the activity of:
(A) Neutral metalloproteases found within the cytoplasm
(B) Basic serine proteinases active in alkaline conditions
(C) Various amylases involved in carbohydrate breakdown
(D) Acidic cysteine and aspartic proteinases

2002

169. By what pathway does the massive flow of sucrose move from the scutellum to the growing radicle and plumule?
(A) Through newly differentiated phloem sieve elements in the embryonic axis
(B) Exclusively through the apoplast via various sugar transporters
(C) By simple diffusion through the various intercellular air spaces
(D) Via direct cell-to-cell transfer solely through plasmodesmata

2022

170. Which specific physical condition in the endosperm heavily represses the secretion of α -amylase from the aleurone layer?
(A) High levels of internal oxygen availability within the seed
(B) Extremely low environmental temperatures during hydration
(C) High concentrations of stored starch within the endosperm
(D) High osmotic potential caused by excess accumulated sugars

2005

171. The DELLA proteins inhibit seed germination. How does GA signaling directly remove this inhibition?
(A) By sequestering the DELLA proteins in the cellular vacuole
(B) By promoting the polyubiquitination and subsequent proteasomal degradation of DELLA
(C) By inducing a mutation within the DELLA encoding gene
(D) By converting the DELLA protein into an active enzyme form

2017

172. Seeds possessing a water-impermeable seed coat (physical dormancy) possess a specialized structure that eventually acts as an environmental water gap. What is a common example of this structure?
(A) The plumule
(B) The aleurone
(C) The scutellum
(D) The strophiole (or lens)

2025

173. What is the distinguishing feature between primary and secondary dormancy?
(A) Primary dormancy involves the embryo; secondary involves the seed coat
(B) Primary dormancy develops during seed maturation; secondary is induced after dispersal by adverse conditions
(C) Primary dormancy only occurs in monocots; secondary only in dicots
(D) Primary dormancy is easily broken by water; secondary cannot be broken

NODIA

2015

174. Which transcription factor plays a central role in mediating ABA signaling to maintain seed dormancy and prevent precocious germination?
(A) ABI3 (ABA Insensitive 3)
(B) GA-MYB
(C) LEAFY
(D) PHYB

2003

175. Match the following chemical dormancy-breaking agents (List-I) with their primary proposed physiological action (List-II).
List I: (Chemical Agent)
P. Gibberellic Acid (GA3)
Q. Potassium Nitrate (KNO3)
R. Thiourea
S. Sulfuric Acid (H2SO4)
List II: (Physiological Action)
1. Overcomes physiological dormancy via pentose phosphate pathway stimulation
2. Erode impermeable seed coats
3. Interacts with light signaling and alters nitrogen metabolism
4. Directly substitutes for endogenous hormone

(B) They are too small to be handled effectively by automated systems
(C) They possess thick seed coats that physically destroy storage containers
(D) They cannot survive drying to the low moisture contents necessary for sub-zero storage

2024

118. Sucrose is crucial during the later stages of orthodox seed maturation because it:
(A) Triggers the immediate enzymatic breakdown of internal proteins
(B) Replaces all the structural cellulose in the cell wall
(C) Acts as the primary metabolic signal required to induce vivipary
(D) Contributes to intracellular vitrification and stabilizes membranes

2010

119. The Tetrazolium (TZ) test relies on the reduction of colorless 2,3,5-triphenyl tetrazolium chloride to which red-colored, insoluble compound?
(A) Carotene
(B) Formazan
(C) Anthocyanin
(D) Lycopene

2010

120. Consider the following statements regarding the triphasic curve of water uptake:
I. Phase I is purely a physical process driven by matric potential.
II. Phase II involves rapid volume expansion and cell division.
III. Phase III coincides with radicle emergence.
Which of the above statements are correct?
(A) II
(B) I and III
(C) III
(D) I

2016

121. The shift from anaerobic to aerobic respiration during early germination is marked by a sharp decline in the activity of which enzyme?
(A) Cytochrome c oxidase
(B) Alcohol dehydrogenase
(C) Citrate synthase
(D) Succinate dehydrogenase

2004

122. During beta-oxidation in glyoxysomes, fatty acids are sequentially degraded into two-carbon units in the form of:
(A) Pyruvate
(B) Acetyl-CoA
(C) Oxaloacetate
(D) Glyceraldehyde 3-phosphate

2021

123. The complete breakdown of native starch grains in cereal endosperms requires the combined action of multiple enzymes. Which enzyme is responsible for the final conversion of maltose to glucose?
(A) Limit dextrinase
(B) α-amylase
(C) Pullulanase
(D) α-glucosidase (maltase)

2019

124. Which protease type is primarily responsible for the initial processing of large, insoluble globulin complexes in legume seeds?
(A) Neutral exopeptidases
(B) Basic aminopeptidases
(C) Carboxypeptidases
(D) Acidic endopeptidases

2023

125. The transport of amides and ureides to the growing seedling axis is essential because the emerging seedling initially lacks:
(A) The immediate ability to perform efficient photosynthesis
(B) The full genetic code required for de novo protein synthesis
(C) Sufficient internal water stores for complete hydration
(D) A functional root system to absorb exogenous soil nitrogen

2010

126. In addition to secreting hydrolytic enzymes, the aleurone layer of cereals also stores significant quantities of phytic acid, which serves as a reserve for:
(A) Nitrogen
(B) Simple sugars
(C) Free fatty acids
(D) Phosphorus and mineral cations

2011

127. Which intracellular signaling molecule acts as a secondary messenger in the GA-induced signal transduction pathway within aleurone cells?
(A) Ethylene gas
(B) Salicylic acid
(C) Starch
(D) cGMP and Calcium (Ca^{2+})

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2014

128. Physiological dormancy is the most common form of dormancy in temperate species. It is primarily driven by:
(A) The presence of a thick, woody pericarp surrounding the seed
(B) Endogenous chemical blocks within the embryo or enclosing tissues
(C) The complete and total absence of a functional embryonic axis
(D) Severe dehydration beyond standard orthodox limits

2023

129. Thermoinhibition, where seeds are prevented from germinating at unseasonably high temperatures, is a classic example of:
(A) Primary physical dormancy
(B) Morphological dormancy
(C) Parthenocarpy
(D) Induced secondary dormancy

2018

130. Match the seed question component (List-I) with its primary storage substance (List-II).
List I: (Seed Component)
P. Aleurone layer
Q. Scutellum
R. Starchy endosperm
S. Cotyledons of legumes
List II: (Storage Substance)
1. Globulin proteins
2. Lipids and specific vitamins
3. Phytic acid and specific proteins
4. Starch
(A) P-3, Q-2, R-4, S-1
(B) P-2, Q-3, R-1, S-4
(C) P-4, Q-1, R-3, S-2
(D) P-1, Q-4, R-2, S-3

2009

131. Which mechanical method is effectively used to break physical dormancy caused by a hard seed coat?
(A) Immersion of the seeds into a bath of liquid nitrogen
(B) Exposure of the seeds to a specific intensity of red light
(C) Treatment of the seeds with a solution of gibberellic acid
(D) Rubbing seeds on abrasive paper (scarification)

2006

132. During dry after-ripening, the gradual accumulation of reactive oxygen species (ROS) in a tightly controlled manner acts as a positive signal to:
(A) Destroy all forms of embryonic DNA during storage
(B) Strengthen the seed coat to prevent early germination
(C) Initiate the immediate synthesis of storage starch
(D) Alleviate dormancy by altering hormonal sensitivity

2002

133. Which group of plants typically produces exalbuminous seeds where the cotyledons serve as the sole massive storage organs?
(A) Gramineae (Grasses)
(B) Orchidaceae (Orchids)
(C) Fabaceae (Legumes)
(D) Liliaceae (Lilies)

2019

134. During the early globular stage of embryogenesis, the outer layer of cells differentiates into the:
(A) Procambium
(B) Ground meristem
(C) Suspensor
(D) Protoderm

2014

135. Assimilate transport into the developing endosperm relies heavily on cell wall invertase. What is the consequence of silencing the cell wall invertase gene during seed filling?
(A) Accelerated seed maturation and premature shedding of the fruit
(B) Seed abortion or significantly reduced seed size (shrunken seeds)
(C) Formation of giant seeds with excessive storage of simple sugars
(D) Increased lipid accumulation instead of starch

2013

136. Seed lipids are predominantly stored as triacylglycerols (TAGs). What is the basic chemical structure of a TAG?
(A) Three fatty acids esterified to a glycerol backbone
(B) Three glycerol molecules bound to one fatty acid
(C) A single fatty acid chain bound to a phosphate group
(D) A cholesterol backbone with three attached fatty acids

NODIA

2018

137. Which statement best describes the physical structure of an oleosome (oil body)?
(A) A lipid core surrounded by a phospholipid half-unit membrane coated with oleosins
(B) A lipid core surrounded by a complete phospholipid bilayer and embedded aquaporins
(C) An empty vacuole that temporarily fills with free fatty acids
(D) A solid crystalline matrix of pure saturated fats

2022

138. The physiological onset of maturation drying is usually preceded by the seed achieving:
(A) Maximum water content within the developing embryo
(B) Complete degradation of its chlorophyll
(C) Emergence of the radicle through the protective seed coat
(D) Physiological maturity (maximum dry weight)

2011

139. Which of the following is a classic example of an intermediate seed species?
(A) Zea mays (Maize)
(B) Coffea arabica (Coffee)
(C) Triticum aestivum (Wheat)
(D) Quercus robur (Oak)

2002

140. Consider the following statements regarding LEA proteins:
I. They are intrinsically disordered proteins.
II. They fold into structured conformations upon desiccation.
III. They promote the crystallization of intracellular solutes.
IV. They are synthesized late in embryogenesis.
Which of the above statements are correct?
(A) I, II and IV
(B) II, III and IV
(C) I, III and IV
(D) I and IV

2010

141. The rate of seed aging during storage is exponentially increased by elevating which two environmental factors?
(A) Light intensity and oxygen concentration
(B) Atmospheric pressure and carbon dioxide
(C) Nitrogen gas and chilling
(D) Temperature and moisture content

2002

142. During Phase I of imbibition, water uptake occurs rapidly and is generally considered to be:
(A) Strictly reliant on the presence of oxygen
(B) Blocked entirely by standard seed coats in all species
(C) Driven solely by active solute transport
(D) Independent of the seed's viability

2001

143. Which metabolic pathway primarily generates the reducing power (NADPH) required for biosynthetic reactions during early germination?
(A) The Tricarboxylic Acid (TCA) cycle
(B) Glycolysis
(C) Beta-oxidation
(D) The Oxidative Pentose Phosphate Pathway (OPPP)

2018

144. Gluconeogenesis in the germinating seed involves the conversion of oxaloacetate to phosphoenolpyruvate (PEP). Which enzyme catalyzes this specific crucial step?
(A) PEP carboxylase
(B) Pyruvate kinase
(C) Malate dehydrogenase
(D) PEP carboxykinase (PEPCK)

2008

145. What structural feature of the amylopectin molecule prevents pure α-amylase from completely degrading it to free glucose?
(A) The presence of α-1,6 branch points
(B) The lack of α-1,4 linkages
(C) Its association with cellulose
(D) The presence of beta linkages

2005

146. Which class of proteinases relies on a specific sulfur-containing amino acid at its active site and is abundant in germinating seeds?
(A) Serine proteinases
(B) Aspartic proteinases
(C) Metallo-proteinases
(D) Cysteine proteinases

2010

147. To prevent localized osmotic stress, high concentrations of mobilized sugars in the endosperm are rapidly:
(A) Converted into large insoluble starch grains within the endosperm
(B) Excreted out of the seed into the surrounding soil environment
(C) Loaded into the scutellum and converted

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(C) A perfectly permeable seed coat enclosing a dead embryo
(D) The presence of deep physical grooves on the seed surface

2013

107. Primary dormancy in seeds is biologically advantageous because it:
(A) Ensures all seeds germinate immediately upon shedding
(B) permanently prevents germination, serving only as a food source for herbivores
(C) Accelerates the aging process of the seed
(D) Prevents vivipary and delays germination until conditions are likely favorable

2006

108. The ABA/GA ratio is the critical determinant of seed dormancy. A sudden drop in this ratio typically results in:
(A) Deepening of primary dormancy
(B) Initiation of germination
(C) Immediate death of the embryo
(D) Formation of a harder seed coat

2023

109. Stratification is an artificial technique used to break dormancy. What environmental condition does it simulate?
(A) A dry, hot summer
(B) Passing through the digestive tract of an animal
(C) A severe forest fire
(D) Overwintering under cool, moist conditions

2014

110. How do transcriptomic changes during after-ripening alter seed physiology?
(A) By completely ceasing all forms of internal gene expression
(B) By switching the genetic code from DNA to RNA permanently
(C) By synthesizing a completely new seed coat layer internally
(D) By reducing the sensitivity of the embryo to ABA and increasing sensitivity to GA

2022

111. Which term describes a seed that develops without fertilization but maintains standard seed structure and physiology?
(A) Viviparous seed
(B) Apomictic seed
(C) Recalcitrant seed
(D) Parthenocarpic fruit

2024

112. The basal cell formed after the first zygotic division in dicots typically develops into the:
(A) Shoot apical meristem
(B) Suspensor
(C) Cotyledons
(D) Aleurone layer

2006

113. Phloem unloading in the developing seed of most dicots must include an apoplastic step because:
(A) The symplast is physically blocked by lignin deposition early in development
(B) Maternal and embryonic tissues have incompatible cytoplasm
(C) The apoplast contains highly active enzymes that construct proteins
(D) There are no plasmodesmata connecting maternal tissue and embryonic tissue

2018

114. Cereal endosperms are generally deficient in which essential amino acid, a fact related to their specific prolamin content?
(A) Glutamine
(B) Proline
(C) Leucine
(D) Lysine

2022

115. Within the seed, what structural configuration allows starch granules to exhibit a characteristic Maltese cross under polarized light?
(A) The random dispersal of free glucose
(B) The radial orientation of amylopectin crystals
(C) The presence of oleosins on the granule surface
(D) The surrounding lipid bilayer

2014

116. Cell expansion during seed development is primarily driven by the massive influx of:
(A) Water and the accumulation of storage compounds
(B) Air into the various intracellular spaces of the embryo
(C) Mineral calcium to harden the walls
(D) Lignin precursors that strengthen the cellular framework

2005

117. Which characteristic makes recalcitrant seeds exceptionally difficult to store in standard genebanks?
(A) They require constant exposure to light

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(D) Hypocotyl-radicle axis and cotyledons

2008

157. Which membrane-bound transporter is critical for the active uptake of sucrose into the cotyledons or endosperm from the apoplastic space during seed filling?
(A) PIN proteins involved in the transport of various auxins
(B) Aquaporins that facilitate the movement of water molecules
(C) NRT (Nitrate Transporters) for the uptake of nitrogen
(D) SUT (Sucrose Transporter) / SUC

2025

158. Which Osborne fraction encompasses the major storage proteins of legumes, such as phaseolin and legumin?
(A) Globulins
(B) Albumins found in the aqueous layer
(C) Prolamins typically found in cereals
(D) Glutelins soluble in dilute acids

2019

159. The biogenesis of starch granules occurs within the amyloplast stroma. Which enzyme complex initiates the synthesis of the amylose polymer?
(A) Soluble starch synthase
(B) Starch branching enzyme
(C) Isoamylase
(D) Granule-bound starch synthase (GBSS)

2016

160. Consider the following events occurring during the reserve accumulation phase:
I. Cell division arrests and cell expansion dominates.
II. Massive synthesis of storage proteins and lipids.
III. The seed achieves its maximum fresh weight.
IV. Vascular connections to the mother plant are completely severed early in the phase.
V. Starch synthesis occurs at maximum rates.
Which of the above statements are correct?
(A) I, II, III and V
(B) II, III, IV and V
(C) I, III, IV and V
(D) I, II and IV

2005

161. Recalcitrant seeds cannot undergo maturation drying. Consequently, they are shed from the mother plant at a moisture content typically ranging from:
(A) 0-5%
(B) 5-15%
(C) 15-30%
(D) 30-70%

2012

162. How does the accumulation of non-reducing sugars facilitate desiccation tolerance?
(A) By forming a biological glass that severely restricts molecular mobility
(B) By undergoing rapid fermentation to produce internal metabolic heat
(C) By functioning as the primary structural components of the cell wall
(D) By breaking down immediately to release stores of pure water

2003

163. The principle of the accelerated aging (AA) test for seed vigor relies on subjecting seeds to brief periods of:
(A) High temperature and high relative humidity
(B) Sub-zero temperatures and high vacuum
(C) Intense UV radiation
(D) Total submersion in hypertonic saline

2003

164. During which phase of seed hydration does the synthesis of massive amounts of new mRNA and proteins essential for radicle protrusion occur?
(A) Early Phase I
(B) Late Phase III
(C) Pre-imbibition phase
(D) Phase II (Lag phase)

NODIA

2002

165. What is the immediate physiological consequence of the radicle penetrating the seed coat (entry into Phase III)?
(A) Resumption of massive water uptake primarily driven by solute potential
(B) A complete and total halt in all internal respiration processes
(C) The immediate degradation of all internal mitochondria
(D) Reversion to an entirely anaerobic form of cellular metabolism

2005

166. Beta-oxidation breaks down long-chain fatty acids. Where does this process primarily localize in the cells of germinating oilseeds?
(A) Chloroplasts
(B) Nucleus
(C) Glyoxysomes
(D) Vacuoles

2023

185. In highly deteriorated, aged seeds, the tetrazolium test typically yields which visual result?
(A) Pale, patchy, or entirely absent staining in critical embryonic regions
(B) Uniform, bright carmine red staining across the entire embryo
(C) Intense blue staining of the endosperm
(D) Rapid dissolution of the seed structure

2023

186. Which parameter of seed water potential must become less negative than the surrounding soil potential for water imbibition (Phase I) to cease initially?
(A) Matric potential
(B) Osmotic potential
(C) Gravitational potential
(D) Total water potential

2018

187. The cyanide-resistant alternative oxidase (AOX) pathway in seed respiration is particularly active during early germination. What is its primary physiological role?
(A) Generating heat and maintaining electron flux when cytochrome c oxidase is limited or inhibited
(B) Maximizing the overall synthesis of ATP within the mitochondria
(C) Synthesizing cyanide to kill various invading soil pathogens
(D) Activating the TCA cycle directly during the initial hydration

2014

188. Which transport metabolite crosses the glyoxysome membrane into the cytosol to continue the process of gluconeogenesis?
(A) Citrate
(B) Acetyl-CoA
(C) Succinate
(D) Fructose

2011

189. Which characteristic defines β-amylase as an exoenzyme?
(A) It cleaves maltose units strictly from the non-reducing ends of starch chains
(B) It cleaves internal α-1,4 bonds randomly within the starch chain
(C) It cleaves branch points centrally located in the amylopectin molecule
(D) It degrades cellulose only from the outside inwards to release sugars

2003

190. Protein mobilization yields high quantities of toxic ammonium ions. How does the germinating seed detoxify and transport this nitrogen?
(A) By assimilating it into amides like glutamine via glutamine synthetase
(B) By excreting gaseous ammonia through the seed coat
(C) By converting it directly into nitrogen gas
(D) By storing it permanently in the vacuole

2024

191. During the transport of mobilized reserves in cereal grains, the scutellum acts as a strong:
(A) Sink for simple sugars from the endosperm, and subsequently a source for the embryonic axis
(B) Source tissue for structural cellulose found in the axis
(C) Barrier that prevents any form of sugar transport to the axis
(D) Primary site of photosynthesis for the germinating seedling

2021

192. Read the following statements and select the correct option.
Assertion (A): The aleurone layer of a mature cereal grain consists of living cells capable of active protein synthesis.
Reason (R): The aleurone cells survive maturation drying, unlike the bulk of the starchy endosperm which undergoes programmed cell death.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2012

193. GA-induced signaling in seeds involves the targeted destruction of repressors. Which cellular machinery is directly responsible for degrading the DELLA proteins?
(A) The 26S proteasome
(B) The lysosome
(C) The vacuole
(D) The Golgi apparatus

2018

194. Which of the following defines physiological dormancy (PD)?
(A) The embryo is fully mature but physically prevented from expanding by a hard, woody coat

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synthesis
(A) P-4, Q-3, R-1, S-2
(B) P-3, Q-4, R-2, S-1
(C) P-1, Q-2, R-3, S-4
(D) P-2, Q-I, R-4, S-3

2006

176. Which subtle cellular event correlates strongly with the loss of dormancy during the dry after-ripening process?
(A) Targeted oxidation of specific dormancy-associated mRNAs and proteins
(B) Complete rehydration of the embryonic axis within the seed coat
(C) The division of the root apical meristem cells in the embryo
(D) The physical splitting of the seed coat due to internal pressure

2021

177. The term "perisperm" refers to seed storage tissue derived from which maternal structure?
(A) The ovary wall
(B) The endosperm
(C) The suspensor
(D) The nucellus

2015

178. During seed development, what prevents the immature embryo from germinating viviparously?
(A) A peak in endogenous Abscisic Acid (ABA) and high osmotic potential
(B) The complete and total absence of any available internal water
(C) A peak in the level of endogenous gibberellins within the seed
(D) The extreme hardness of the pericarp surrounding the embryo

2006

179. In cereal grains, assimilate transport involves a symplastic discontinuity. Where is this discontinuity typically located?
(A) Between the maternal nucellar projection and the endosperm
(B) Between the aleurone layer and the starchy endosperm
(C) Between the scutellum and the embryo axis
(D) Between the coleoptile and the first leaf

2005

180. Wheat gluten, critical for dough elasticity, is primarily composed of which two Osborne protein fractions?
(A) Albumins and Globulins that are soluble in various aqueous solutions
(B) Globulins and Gliadins that contribute to the nutritional profile
(C) Albumins and Glutenins that are involved in the metabolic activity
(D) Gliadins (Prolamins) and Glutenins (Glutelins)

2005

181. What prevents intrinsic lipases from degrading stored lipids prematurely during seed development?
(A) Lipases and lipid droplets are spatially separated or lipases are kept inactive
(B) Lipids are synthesized only after the process of germination
(C) Oleosins act as enzymes that effectively destroy internal lipases
(D) The internal pH is too basic for any form of lipase activity

2007

182. Select the correct sequence of events in the mobilization of stored lipids:
(A) Triacylglycerol hydrolysis → Beta-oxidation → Glyoxylate cycle → Gluconeogenesis
(B) Beta-oxidation → Glyoxylate cycle → Triacylglycerol hydrolysis → Gluconeogenesis
(C) Glyoxylate cycle → Beta-oxidation → Gluconeogenesis → Triacylglycerol hydrolysis
(D) Gluconeogenesis → Triacylglycerol hydrolysis → Beta-oxidation → Glyoxylate cycle

2003

183. Which morphological trait is commonly observed in recalcitrant seeds compared to orthodox seeds?
(A) Much smaller average seed mass compared to standard orthodox types
(B) Substantially larger size and lack of a severe maturation drying phase
(C) Extremely thick, water-impermeable seed coats that prevent drying
(D) The complete and total absence of cotyledons within the mature seed

2013

184. The vitrification (glassy state) of the seed cytoplasm during desiccation depends primarily on the proper ratio of:
(A) Starches to lipids
(B) Proteins to nucleic acids
(C) Calcium to magnesium
(D) Oligosaccharides to water

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back to transportable sucrose
(D) Evaporated from the seed coat as a form of metabolic water

2022

148. Read the following statements and select the correct option.
Assertion (A): The scutellum of the cereal grain undergoes significant morphological changes during germination, including the elongation of epithelial cells.
Reason (R): These elongated epithelial cells form a haustorium-like structure to maximize surface area for absorbing mobilized nutrients.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2008

149. The process by which the embryo signals the aleurone layer involves the release of GA. How does the aleurone layer ensure massive α -amylase synthesis?
(A) By degrading all of its pre-existing and current mRNA transcripts
(B) By converting structural proteins directly into enzymes
(C) By importing various enzymes directly from the surrounding soil
(D) By massively upregulating the transcription of specific α-amylase genes

2002

150. Morphological dormancy is characterized by an underdeveloped embryo. Which of the following plant families frequently exhibits this type of dormancy?
(A) Gramineae (Grasses)
(B) Fabaceae (Legumes)
(C) Brassicaceae (Mustards)
(D) Apiaceae (Umbellifers)

2015

151. Which factor is fundamentally responsible for initiating primary dormancy during seed development?
(A) High levels of endogenously synthesized ABA in the developing seed
(B) Extreme cold exposure experienced by the mother plant during growth
(C) High levels of exogenous gibberellins applied to the developing fruit
(D) The physical rupture of the seed coat prior to the shedding process

2022

152. According to the hormonal balance theory of seed dormancy, what represents the germination-permissive state?
(A) High ABA / Low GA
(B) Low ABA / Low GA
(C) Low ABA / High GA
(D) High ABA / High GA

2009

153. Exogenous application of which nitrogenous compound is often used to break dormancy and stimulate uniform germination in various crops?
(A) Ammonium chloride
(B) Urea
(C) Sodium nitrite
(D) Potassium nitrate (KNO3)

2006

154. After-ripening represents a period during which seeds lose primary dormancy while maintained in a dry state. Which moisture content range is generally optimal for after-ripening in orthodox seeds?
(A) 0-2%
(B) 5-15%
(C) 30-40%
(D) 50-60%

2010

155. Which of the following best contrasts albuminous and exalbuminous seeds?
(A) Albuminous seeds retain endosperm; exalbuminous seeds consume it during development
(B) Albuminous seeds lack a seed coat; exalbuminous seeds have one
(C) Albuminous seeds are exclusively monocots; exalbuminous are exclusively dicots
(D) Albuminous seeds cannot germinate; exalbuminous seeds can

2015

156. In standard dicot embryogenesis, the transition from the heart stage to the torpedo stage is primarily characterized by the directed expansion of the:
(A) The physical expansion of the suspensor anchoring the embryo
(B) The cellular division of the persistent endosperm tissue
(C) The thickening of the protective seed coat layer

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(B) The embryo has a low growth potential that cannot overcome the mechanical restraint of the tissues
(C) The embryo is completely degraded and requires time to regenerate during the hydration phase
(D) The seed possesses a massive endosperm that is chemically toxic to the developing embryo

2016

195. Light-sensitive (photoblastic) seeds require light for germination. Which photoreceptor primarily controls this process by shifting to an active form under red light?
(A) Phytochrome
(B) Cryptochrome
(C) Phototropin
(D) UVR8

2005

196. An increase in the ABA/GA ratio during seed development corresponds directly to the:
(A) Immediate onset of germination
(B) Degradation of all storage proteins
(C) Rupture of the seed coat
(D) Induction and maintenance of primary dormancy

2006

197. Mechanical scarification is generally an inappropriate treatment for which type of dormancy?
(A) Physical dormancy
(B) Morphophysiological dormancy
(C) Hard seededness in legumes
(D) Dormancy caused by macrosclereids

2023

198. Dry after-ripening alters the seed's hormonal sensitivity. Typically, an after-ripened seed shows:
(A) Decreased sensitivity to ABA and increased sensitivity to GA
(B) Increased sensitivity to ABA and decreased sensitivity to GA
(C) Absolute and total insensitivity to all classes of plant hormones
(D) Absolute reliance on the presence of exogenous ethylene for growth

2018

199. Which defining characteristic applies to a dicotyledonous albuminous seed, such as Ricinus communis (Castor)?
(A) It lacks cotyledons entirely throughout its embryogenesis and growth
(B) It stores its massive reserves almost entirely within its enlarged cotyledons
(C) It germinates viviparously without undergoing any form of a dormant phase
(D) It possesses broad, thin cotyledons that absorb reserves from a persistent endosperm during germination

2019

200. During seed embryogenesis, the root apical meristem (RAM) is derived primarily from the:
(A) The shoot apical meristem of the seedling
(B) The upper tier of cells in the proembryo
(C) The aleurone layer of the endosperm
(D) Hypophysis, a derivative of the suspensor

2007

201. Which structural barrier necessitates specialized transfer mechanisms for assimilates moving from maternal to filial tissues in developing seeds?
(A) The lack of symplastic continuity (plasmodesmata) between maternal and filial generations
(B) The complete and total absence of any functional cell walls
(C) The highly lignified xylem connections that block all movement
(D) The extreme thickness of the protective cuticle layer found there

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2010

202. The protein fraction classified as "Glutelins" by Osborne is best known for being:
(A) Soluble in pure water
(B) Soluble in high-concentration salt solutions
(C) Soluble in dilute acids and bases
(D) Completely insoluble in all known solvents

2023

203. Oleosins serve a critical function during seed desiccation by preventing the coalescence of oil bodies. What structural feature of the oleosin protein allows this?
(A) A highly hydrophilic core domain embedded in the lipid matrix
(B) A long central hydrophobic domain that anchors into the lipid, with hydrophilic ends facing the cytosol
(C) A pure carbohydrate composition that forms a rigid outer barrier
(D) Its ability to form a solid crystalline shell like a viral capsid

27. (D) Amyloplasts
Starch is primarily synthesized and stored within specialized plastids called amyloplasts. During seed development, glucose units are polymerized into amylose and amylopectin, which then aggregate to form semi-crystalline starch granules within the stroma of these organelles. Amyloplasts are particularly abundant in the endosperm or cotyledons of storage-rich seeds, serving as the major energy source for the germinating embryo.

28. (A) Water potential
During the final maturation drying phase of seed development, the water potential of the seed tissues decreases sharply. This drop occurs as the seed loses moisture to reach equilibrium with the surrounding environment, often resulting in a highly desiccated state. This physiological change is essential for the transition into a quiescent or dormant state, ensuring the long-term survival of orthodox seeds.

29. (B) Tropical rainforests
Recalcitrant seeds, which are highly sensitive to desiccation and cannot survive significant water loss, are most commonly found in tropical rainforest environments. In these consistently moist and warm habitats, seeds often lack a dormant phase and germinate almost immediately after shedding. This ecological strategy is adapted to conditions where water is rarely limiting, making severe desiccation tolerance unnecessary for the species' survival.

30. (B) By replacing water molecules and hydrogen-bonding to membrane phospholipids
Non-reducing sugars like trehalose and sucrose protect cellular structures during seed desiccation through a mechanism known as the water replacement hypothesis. These sugars form hydrogen bonds with the polar head groups of membrane phospholipids, effectively replacing the hydration shell of water molecules. This stabilizes the membrane structure, preventing phase transitions and fusion that would otherwise lead to cellular death during drying.

31. (A) Lipid peroxidation by reactive oxygen species
A primary cause of seed deterioration and loss of viability during storage is the peroxidation of lipids by reactive oxygen species. This biochemical process damages cellular membranes, leading to increased solute leakage and impaired organelle function. Over time, the accumulation of oxidative damage to proteins and nucleic acids further compromises the seed's ability to initiate and complete the complex process of germination.

32. (C) Matric potential
The principal driving force for water uptake during the initial phase of seed hydration, known as imbibition, is the matric potential. This potential arises from the strong affinity of water for the dry macromolecules and cell wall components within the seed, such as proteins and polysaccharides. Because the seed is extremely dry, the matric potential is very low, creating a steep gradient.

33. (A) P-4, Q-2, R-1, S-3
In the sequence of seed germination, rapid initial water uptake occurs during Phase I, driven by matric forces. The transition from Phase I to II is marked by the reactivation of pre-existing enzymes. Phase II involves major mitochondrial biogenesis and metabolic preparation, although external water uptake is minimal. Finally, Phase III is defined by radicle emergence and the resumption of rapid water uptake.

34. (C) Cytosol
The conversion of stored lipids into sucrose involves a collaborative pathway between glyoxysomes, mitochondria, and the cytosol. Following the breakdown of fatty acids in glyoxysomes and the transport of succinate to mitochondria, the final steps of gluconeogenesis occur in the cytosol. This integrated process ensures that lipid energy reserves are efficiently converted into a transportable sugar to support the growth of the seedling.

35. (B) Hydrolysis of maltose into free glucose molecules
During carbohydrate breakdown in germinating seeds, alpha-glucosidase plays a final and essential role by hydrolyzing maltose into two free glucose molecules. While amylases break down large starch polymers into smaller dextrins and maltose, they cannot complete the saccharification process alone. Alpha-glucosidase ensures that the carbohydrate reserves are fully converted into simple glucose, which is then available for respiration and growth.

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2005

214. Which tissue plays the dual role of synthesizing hydrolytic enzymes and acting as an absorptive haustorium in a cereal grain?
(A) The starchy endosperm
(B) The scutellum
(C) The coleorhiza
(D) The aleurone layer

2021

215. Match the transcription factor/protein (List-I) to its functional role in the GA signaling pathway in seeds (List-II).
List I: (Transcription Factor / Protein)
P. GID1
Q. DELLA
R. GA-MYB
S. SCF complex
List II: (Functional Role)
1. Soluble receptor that binds Gibberellin
2. Transcription factor that binds the α -amylase promoter
3. Repressor protein that inhibits GA responses
4. Mediates polyubiquitination of the repressor
(A) P-1, Q-3, R-2, S-4
(B) P-3, Q-1, R-4, S-2
(C) P-2, Q-4, R-1, S-3
(D) P-1, Q-4, R-3, S-2

2004

216. Which of the following defines morphological dormancy?
(A) The seed coat is entirely impermeable to the movement of gases and water
(B) The embryo is undifferentiated or rudimentary and requires time to grow inside the imbibed seed before germination
(C) The seed requires a sharp alternating temperature regime to soften the micropyle
(D) The seed possesses a dominant hypocotyl that prevents radicle emergence

2014

217. When a deeply dormant seed is buried in the soil and exposed to seasonal cycles, it may transition into and out of dormancy. This acquired dormancy is known as:
(A) Primary dormancy
(B) Morphological dormancy
(C) Somatic embryogenesis
(D) Secondary dormancy

2006

218. The molecular mechanism underlying dormancy release often involves the degradation of which hormone's signaling factors?
(A) Abscisic acid
(B) Ethylene
(C) Gibberellins
(D) Cytokinins

2009

219. Cold stratification is highly effective at breaking physiological dormancy because it leads to:
(A) The immediate and physical breakdown of the hard seed coat layer
(B) A massive increase in the rate of ABA biosynthesis
(C) The physical freezing and shattering of the internal embryonic axis
(D) An upregulation of GA biosynthesis and increased GA sensitivity

2009

220. Which of the following biochemical changes is a well-documented outcome of the dry after-ripening process in dormant seeds?
(A) The complete hydrolysis of internal starch into glucose units
(B) The initiation of vigorous cell division in the radicle meristem
(C) The de novo synthesis of a secondary seed coat within the shell
(D) Selective non-enzymatic oxidation of specific dormancy-related proteins

NODIA

2016

221. Which functional term describes seeds that rely exclusively on the cotyledons for reserve storage, having completely consumed the endosperm?
(A) Endospermic seeds that retain a large volume of endosperm tissue
(B) Exalbuminous
(C) Albuminous seeds that maintain persistent nutritional reserves
(D) Perispermic seeds derived from the maternal nucellar tissue

2018

222. At which stage of embryonic development is the basic tissue patterning (protoderm, ground meristem, procambium) fully established?
(A) Zygotic stage
(B) Late torpedo stage
(C) Mature stage
(D) Globular stage

2024

223. What primary mechanism drives the bulk flow of assimilates into the seed coat phloem before unloading?
(A) Simple diffusion across a concentration

2008

204. During the maturation drying phase, the seed's metabolic rate fundamentally changes. Which statement best describes this change?
(A) Metabolic processes shut down completely, entering a state of suspended animation (quiescence)
(B) Metabolic rate increases exponentially to combat the rapid water loss
(C) Respiration switches exclusively to an anaerobic fermentation pathway
(D) The overall photosynthetic rate peaks during this specific dry stage

2003

205. Arrange the events of seed hydration and germination in their typical chronological order:
I. Resumption of high metabolic activity without volume increase
II. Rapid initial imbibition driven by matric forces
III. Emergence of the radicle through the seed coat
IV. Sustained rapid water uptake driven by solute potential
(A) I, II, III, IV
(B) II, I, III, IV
(C) II, III, I, IV
(D) I, III, II, IV

2017

206. Which class of molecules provides the primary structural stabilization for cellular membranes when standard hydration shells are lost during severe desiccation?
(A) Specialized lipases that degrade lipids for metabolic energy
(B) Free amino acids that act as temporary structural buffers
(C) Non-reducing sugars (e.g., sucrose, trehalose)
(D) Various unsaturated fatty acids that increase fluidity

2002

207. Accelerated seed aging is often characterized by the loss of membrane semi-permeability. What simple test directly measures this degradation?
(A) Electrical conductivity test of seed leachates
(B) Standard germination test
(C) Tetrazolium test
(D) Moisture content determination

2024

208. The transition from Phase I to Phase II of water uptake is strictly governed by:
(A) The physical characteristics of the seed matrices becoming fully hydrated
(B) The complete degradation of all stored lipid reserves in the embryo
(C) The specific light environment surrounding the imbibed seed coat
(D) The complete exhaustion of all internal oxygen during the initial phase

2001

209. Which metabolic ratio increases significantly within minutes of seed imbibition, indicating a rapid shift in cellular energy status?
(A) C/N ratio
(B) ABA/GA ratio
(C) Adenylate Energy Charge (AEC)
(D) Amylose/Amylopectin ratio

2021

210. Which enzyme is primarily responsible for the mobilization of mineral reserves by hydrolyzing phytin stored in the aleurone layer?
(A) Amylase
(B) Phytase
(C) Lipase
(D) Protease

2011

211. Which carbohydrate-degrading enzyme specifically targets the terminal α-1,4 linkages to release the disaccharide maltose?
(A) Limit dextrinase
(B) α-amylase
(C) α-glucosidase
(D) β-amylase

2014

212. Which process ensures the continuous mobilization of protein reserves by preventing end-product inhibition?
(A) Swift translocation of free amino acids and amides to the growing seedling
(B) Rapid incorporation of free amino acids into insoluble granules
(C) Complete destruction of peptidases after their initial function
(D) Excretion of proteins directly into the soil

2003

213. During the germination of grass seeds, which structure is the first to emerge and serves to protect the young radicle?
(A) Coleoptile
(B) Scutellum
(C) Coleorhiza
(D) Epiblast

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ANSWERS

1. (D) A seed where the endosperm is consumed by the developing embryo before maturity
Exalbuminous seeds are defined by the lack of endosperm at maturity because the developing embryo consumes it during the later stages of seed development. Consequently, the nutritional reserves required for germination are stored within the cotyledons rather than a persistent endosperm tissue. This pattern is common in many dicotyledonous plants, including legumes like beans and peas.

2. (C) Heart stage
In dicotyledonous plants, the heart stage of embryogenesis immediately follows the globular stage. This transition is characterized by the initiation of bilateral symmetry as the two cotyledon primordia begin to emerge from the spherical mass of cells. This stage is crucial for establishing the basic architecture of the future seedling and marks a significant developmental shift in the embryo.

3. (B) Apoplastic unloading from maternal tissues before uptake by the endosperm
Phloem unloading in cereal grains typically involves an apoplastic step where assimilates move from the maternal vascular tissues into the apoplast before being absorbed by the filial tissues. This separation is necessary because there are no plasmodesmatal connections between the maternal and embryonic generations. Specialized transport proteins facilitate the uptake of sugars and amino acids into the developing endosperm.

4. (D) Prolamins
According to Osborne's classification, prolamins are the seed storage proteins characterized by their high solubility in aqueous alcohol solutions, typically seventy to eighty percent ethanol. These proteins are particularly abundant in the endosperm of cereal grains like wheat, maize, and barley. They contain high levels of proline and glutamine, which significantly influence the nutritional and functional properties of the grain.

5. (A) Oleosins
Oleosins are specialized integral membrane proteins that stabilize the phospholipid half-unit membrane surrounding seed oil bodies, also known as oleosomes. These proteins possess a unique hydrophobic domain that anchors into the triacylglycerol core, while their hydrophilic ends face the cytosol. This structural arrangement prevents the coalescence of oil droplets during seed desiccation and maintain the integrity of lipid stores.

6. (C) Cell expansion phase
The cell expansion phase is the period during seed development when the maximum accumulation of storage reserves, such as starch, proteins, and lipids, typically occurs. Following the initial histodifferentiation phase, cells in the storage tissues increase in size to accommodate massive quantities of nutrients. This phase is characterized by a rapid increase in the dry weight and volume of the seed.

7. (A) It can tolerate partial desiccation but is injured by freezing temperatures at low moisture
Intermediate seeds exhibit a level of desiccation tolerance that falls between orthodox and recalcitrant types. While they can survive drying to relatively low moisture contents, typically around ten percent, they remain highly sensitive to freezing temperatures when dry. This sensitivity makes long-term conservation in standard seed banks difficult, as conventional sub-zero storage conditions often lead to a rapid loss of viability.

8. (D) They protect cellular structures and proteins from desiccation-induced damage
Late Embryogenesis Abundant proteins are highly hydrophilic molecules that accumulate during the final stages of seed maturation. Their primary physiological function is to protect cellular membranes and proteins from damage caused by severe water loss. By acting as molecular chaperones and contributing to the formation of a biological glass, they ensure that the seed remains viable throughout the dry state.

9. (B) Dehydrogenases
The Tetrazolium test for seed viability relies on the activity of dehydrogenase enzymes, which are part of the respiratory chain in living cells.

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45. (A) I, II, III and V
During embryogenesis, the globular stage involves spherical symmetry and rapid cell division, while the heart stage marks the initiation of bilateral symmetry in dicots. The suspensor provides physical anchoring and nutrient transfer from the mother plant. Finally, mature embryos typically undergo a desiccation phase to reach quiescence. The torpedo stage occurs after the heart stage, making the fourth statement incorrect.

46. (B) It serves as the primary site of phloem unloading from maternal tissue
In the development of many dicotyledonous seeds, the chalazal pad acts as a specialized region for phloem unloading. Since there is no direct vascular connection between the mother plant and the embryo, nutrients must be released from the maternal phloem into the apoplast at this site. From the chalazal region, these assimilates are subsequently absorbed by the filial tissues to support seed growth.

47. (A) Globulins
Globulins are a major class of seed storage proteins that are distinguished by their solubility in dilute saline solutions. They are the predominant storage proteins in many legume seeds and are also found in significant amounts in some cereals like oats and rice. These proteins are typically stored in specialized organelles called protein bodies and are mobilized to provide nitrogen during germination.

48. (A) Histodifferentiation → Reserve accumulation → Maturation drying
Seed maturation follows a precise chronological sequence beginning with histodifferentiation, where the basic embryonic structures are formed. This is followed by the reserve accumulation phase, during which the seed significantly increases in dry weight as starch, proteins, and lipids are stored. The process concludes with maturation drying, where the seed loses water and enters a dormant or quiescent state for dispersal.

49. (D) They contain alternating amorphous and crystalline lamellae
Starch granules exhibit a highly organized ultrastructure characterized by alternating amorphous and crystalline lamellae. These layers result from the specific arrangement of amylopectin molecules, where the branched regions form amorphous zones and the linear segments form crystalline structures. This semi-crystalline nature is responsible for the characteristic birefringence and the Maltese cross pattern observed when starch is viewed under polarized light.

50. (C) They acquire the ability to tolerate severe water loss before shedding
A defining trait of orthodox seeds is their ability to tolerate severe desiccation, allowing them to be dried to very low moisture contents without losing viability. This tolerance is acquired during the final stages of maturation and is often accompanied by the accumulation of protective sugars and proteins. This characteristic enables orthodox seeds to be stored for long periods in cold, dry conditions.

51. (B) Act as molecular chaperones preventing protein aggregation
Heat shock proteins play a crucial role during seed desiccation by acting as molecular chaperones. They help to maintain the proper folding of cellular proteins and prevent their aggregation under the stressful conditions of extreme water loss. By stabilizing the proteome, these proteins ensure that the cellular machinery remains functional and can resume metabolic activity once the seed is eventually rehydrated.

52. (D) Loss of cellular membrane integrity and increased solute leakage
Lipid peroxidation is a major biochemical event in aging seeds, directly causing the loss of cellular membrane integrity. As reactive oxygen species attack polyunsaturated fatty acids, the membranes become leaky and lose their semi-permeable properties. This damage results in increased solute leakage upon imbibition, which can be measured as electrical conductivity, and ultimately leads to a decline in seed vigor and viability.

53. (A) Plasmolysis phase
The standard triphasic curve of seed hydration consists of Phase I (rapid initial imbibition), Phase II (the lag phase), and Phase III (the resumption of water uptake coinciding with radicle emergence). Plasmolysis is not a phase of this process; rather, it is a phenomenon occurring in living cells when they lose water in a hypertonic environment. The triphasic curve describes the hydration of the whole seed.

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mechanical barrier to water and gas entry. While this physical structure is well-documented, the idea that these specific cells synthesize chemical germination inhibitors is incorrect. Physical dormancy is fundamentally a structural issue rather than a chemical inhibition problem, making the assertion true while the reason is false.

19. (B) Dormancy induced in mature, non-dormant seeds by unfavorable environmental conditions
Secondary seed dormancy is a physiological state induced in mature, non-dormant seeds when they are exposed to environmental conditions that are unfavorable for germination. This mechanism allows seeds to remain viable in the soil seed bank until optimal conditions return. It is distinct from primary dormancy, which is established during seed development on the mother plant before the seeds are dispersed.

20. (D) Gibberellins induce dormancy by activating LEA protein synthesis
In seed physiology, hormonal antagonism typically involves abscisic acid promoting dormancy and gibberellins stimulating germination. Gibberellins do not induce dormancy or activate the synthesis of Late Embryogenesis Abundant proteins; instead, they promote the production of enzymes that mobilize reserves. High levels of abscisic acid are responsible for maintaining dormancy and protecting the embryo during the final stages of seed maturation.

21. (A) Warm or cold stratification to allow embryo growth
Morphological dormancy occurs in seeds where the embryo is underdeveloped or rudimentary at the time of dispersal. To overcome this, seeds require specific temperature treatments, such as warm or cold stratification, which provide the time and conditions necessary for the embryo to complete its development. Once the embryo reaches a certain size and maturity, the seed becomes capable of germinating.

22. (C) A shift in transcriptomic profiles and a decrease in sensitivity to ABA
After-ripening is a process that occurs in dry, dormant seeds during storage, leading to a gradual loss of dormancy. At the physiological level, this involves significant changes in gene expression and a notable decrease in the embryo's sensitivity to the inhibitory effects of abscisic acid. These biochemical shifts prepare the seed to respond to germination-promoting signals once water becomes available.

23. (A) Monocot seed - Typically possesses a large scutellum
Monocotyledonous seeds, particularly those in the grass family, are characterized by a single modified cotyledon known as the scutellum. The scutellum serves as a specialized absorptive organ that transfers nutrients from the endosperm to the developing embryo during germination. In contrast, albuminous seeds store food in the endosperm, while exalbuminous seeds consume the endosperm and store reserves in the cotyledons.

24. (D) Elongation of the cotyledons and the primary embryonic axis
In dicot embryogenesis, the transition from the heart stage to the torpedo stage is marked by the significant elongation of the cotyledons and the primary embryonic axis. During the heart stage, the cotyledon primordia first appear, giving the embryo its characteristic shape. In the subsequent torpedo stage, cell expansion and directed growth result in the distinct elongated form of the mature embryo.

25. (A) I
The statement that maternal phloem symplastically unloads directly into the endosperm of dicots is incorrect. In most seeds, there is a distinct lack of symplastic continuity between the maternal and filial tissues, necessitating an apoplastic transport step. Assimilates must be unloaded into the apoplast and then actively taken up by the developing embryo or endosperm through specialized membrane transport proteins.

26. (C) Prolamins and Glutelins
Wheat grains contain storage proteins that are primarily categorized as prolamins and glutelins. The prolamins in wheat are known as gliadins, while the glutelins are called glutenins. Together, these two protein fractions form gluten when mixed with water, which provides the unique elasticity and strength required for bread making. They constitute the majority of the total protein content found in wheat.

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These enzymes reduce the colorless tetrazolium salt into a stable, red-colored compound called formazan. The appearance of this red stain indicates that the tissues are metabolically active and respiratorily functional, thus confirming that the seed is indeed viable.

10. (C) A lag phase with minimal water uptake but high metabolic activity
Phase II of the triphasic water imbibition curve is a critical lag period where the seed shows little to no increase in water content. Despite the lack of external volume change, internal metabolic activity is exceptionally high. During this phase, the seed repairs cellular damage, activates pre-existing enzymes, and initiates the transcription of genes required for radicle emergence and subsequent growth.

11. (D) Reactivation of pre-existing glycolysis and oxidative pentose phosphate pathway enzymes
Upon seed imbibition, the earliest respiratory events occur before the biogenesis of new mitochondria is completed. The seed initially relies on the reactivation of enzymes already present from the maturation phase, specifically those involved in glycolysis and the oxidative pentose phosphate pathway. This immediate metabolic response provides the initial energy and reducing power necessary to drive early cellular repair and germination processes.

12. (B) II and III
During the mobilization of lipid reserves in germinating seeds, the glyoxylate cycle plays a central role by converting acetyl-CoA into succinate within the glyoxysomes. This succinate is then transported to the mitochondria, where it enters the citric acid cycle to provide intermediates for gluconeogenesis. Contrary to some assumptions, beta-oxidation occurs in glyoxysomes rather than mitochondria in these specific plant tissues.

13. (B) Limit dextrinase
Limit dextrinase is the specific debranching enzyme responsible for hydrolyzing the alpha-one-six-glycosidic bonds found at the branch points of amylopectin. While alpha and beta amylases effectively break down the linear alpha-one-four chains, they cannot bypass these branch points. Therefore, limit dextrinase is essential for the complete degradation of starch granules into fermentable sugars like maltose and glucose during germination.

14. (B) They remove amino acids sequentially from the terminal ends of peptide chains
Exopeptidases are a class of proteolytic enzymes that facilitate protein breakdown by sequentially removing single amino acids from the terminal ends of peptide chains. These enzymes include aminopeptidases, which act on the N-terminus, and carboxypeptidases, which target the C-terminus. Their action is crucial for providing a steady supply of free amino acids to the growing embryonic axis for new protein synthesis.

15. (A) Sucrose
In germinating seeds, carbohydrate reserves mobilized from the endosperm or cotyledons are primarily converted into sucrose for transport. Sucrose is a non-reducing sugar that is highly soluble and chemically stable, making it the ideal molecule for translocation through the phloem. Once it reaches the growing embryonic axis, it is broken down to provide energy and carbon skeletons for development.

16. (C) Aleurone layer
The aleurone layer in cereal grains is the specialized secretory tissue responsible for producing and releasing hydrolytic enzymes into the starchy endosperm. In response to gibberellic acid signals from the embryo, aleurone cells synthesize enzymes like alpha-amylase and various proteases. These enzymes break down stored reserves, providing the necessary nutrients to support the early growth and development of the emerging seedling.

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17. (D) It binds to the promoter of the α-amylase gene to induce its transcription
In the gibberellin signaling pathway, the GA-MYB transcription factor plays a pivotal role in regulating reserve mobilization. After gibberellic acid triggers the degradation of repressor proteins, GA-MYB is synthesized and subsequently binds to specific sequence elements in the promoters of hydrolytic enzyme genes. This binding event directly induces the transcription of alpha-amylase, allowing the seed to degrade its starchy reserves.

18. (C) A is true but R is false.
Hard seed coats containing dense macrosclereid cells impose physical dormancy by acting as a

36. (D) Endopeptidases
Endopeptidases are the class of enzymes that initiate the degradation of large, insoluble storage proteins by cleaving internal peptide bonds. This initial action breaks down the complex protein structures into smaller, more soluble peptides. Following this, other enzymes like exopeptidases sequentially remove individual amino acids. This coordinated proteolytic activity is necessary to mobilize nitrogen reserves for the developing embryonic axis during germination.

37. (A) Nitrogen
Amides such as glutamine and asparagine are the primary chemical forms used to transport mobilized nitrogen from the storage tissues to the growing embryonic axis. Nitrogen is a critical nutrient for the synthesis of new proteins, nucleic acids, and chlorophyll in the developing seedling. These amides are highly stable and have a high nitrogen-to-carbon ratio, making them efficient transport molecules.

38. (C) Specialized absorptive organ for mobilized nutrients
In cereal grains, the scutellum is a single, modified cotyledon that functions primarily as a specialized absorptive organ. It is positioned between the starchy endosperm and the embryonic axis. During germination, the scutellum absorbs the sugars, amino acids, and minerals released by the enzymatic breakdown of endosperm reserves, subsequently translocating these vital nutrients to the growing parts of the seedling.

39. (A) DELLA
In the gibberellin signaling pathway, DELLA proteins act as repressors that inhibit the transcription of GA-responsive genes. When gibberellin is perceived by its receptor, it triggers the polyubiquitination and subsequent degradation of these DELLA proteins via the proteasome. This removal of repression allows the transcription of genes, such as those for alpha-amylase, which are essential for reserve mobilization and germination.

40. (D) Physiological dormancy
A seed that fails to germinate because the radicle cannot physically penetrate the surrounding tissues is often exhibiting coat-imposed physiological dormancy. In this state, the embryo lacks the necessary growth potential to overcome the mechanical restraint of the endosperm or seed coat. This form of dormancy is typically broken when internal or external signals increase the embryo's growth force or soften the tissues.

41. (B) Maternal environmental effect
The maternal environmental effect describes how the conditions experienced by the mother plant during seed development influence the degree of dormancy in the resulting seeds. For example, seeds maturing in cool, damp environments often develop stronger primary dormancy compared to those maturing in hot, dry conditions. This phenomenon allows the plant to adapt its offspring's germination timing to local environmental cues.

42. (C) It acts as a signaling molecule to break dormancy and stimulate germination
The exogenous application of potassium nitrate is a widely used technique to stimulate the germination of dormant seeds. It is believed to act as a signaling molecule that interacts with light and hormonal pathways, often reducing the seed's requirement for light or chilling. This treatment helps to synchronize germination across a seed lot, which is particularly useful in agricultural and laboratory settings.

43. (D) Storage in a dry state at room or slightly elevated temperatures
After-ripening is a natural process through which seeds lose their primary dormancy while being maintained in a dry state. This process is most successful when seeds are stored at room temperature or slightly elevated temperatures with low moisture content. Over time, biochemical and transcriptomic shifts occur within the dry seed, eventually allowing it to germinate once it is rehydrated under suitable conditions.

44. (A) A single modified cotyledon called the scutellum
The mature embryo of a typical monocotyledonous seed is characterized by the presence of a single modified cotyledon known as the scutellum. Unlike dicots, which have two cotyledons, monocots use the scutellum to absorb nutrients from the endosperm during germination. This structure is accompanied by the coleoptile and coleorhiza, which protect the emerging shoot and root, respectively, during the early stages of growth.

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gradient
(B) Active transport of water through aquaporins
(C) Capillary action within the xylem vessels
(D) Pressure-driven flow based on Münch's hypothesis

2011

224. Which class of storage proteins dominates in standard dicotyledonous seeds, such as soybeans and peas?
(A) Globulins
(B) Prolamins
(C) Glutelins
(D) Albumins

2015

225. What is the ultrastructural configuration of storage proteins within a protein body?
(A) A highly structured, ordered crystal lattice or an amorphous matrix, often containing inclusions of phytin
(B) A chaotic liquid phase mixed thoroughly with various free fatty acids
(C) A hollow sphere composed exclusively of specialized oleosin proteins
(D) A fibrous network consisting of purely structural cellulose fibers

2006

226. Which physiological shift marks the termination of the reserve accumulation phase and the beginning of maturation drying?
(A) Disconnection of the vascular supply (funiculus abscission)
(B) The physical bursting of the seed coat during the late maturation stage
(C) A sudden and rapid influx of water from the surrounding maternal tissues
(D) Initiation of photosynthesis in the embryo

2018

227. Orthodox seeds undergo intense desiccation, often reaching moisture contents as low as:
(A) 0-1%
(B) 5-15%
(C) 20-30%
(D) 40-50%

2018

228. Which functional group of molecules, heavily synthesized during late maturation, acts as a "molecular shield" preventing protein denaturation during water loss?
(A) Specialized lipases that degrade lipids for metabolic energy
(B) Prolamins that serve as the primary storage protein in cereals
(C) Phytases that catalyze the breakdown of mineral-storing phytin
(D) LEA proteins

2006

229. During seed aging, reactive oxygen species (ROS) primarily target which cellular component, leading to severe structural degradation?
(A) The solid starch granule core
(B) Polyunsaturated fatty acids in cellular membranes
(C) The inert seed coat lignin
(D) The purely crystalline phytin inclusions

2001

230. During the typical Phase II (lag phase) of germination, the seed's fresh weight:
(A) Increases exponentially due to massive water potential gradients
(B) Remains relatively constant while active metabolism and repair occur
(C) Decreases sharply due to rapid respiration and water loss
(D) Fluctuates randomly depending on light availability

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54. (C) The biogenesis and structural repair of mitochondria
The successful transition from glycolysis to the citric acid cycle during seed germination is heavily dependent on the biogenesis and structural repair of mitochondria. During the dry state, mitochondria may be partially degraded or disorganized. Upon imbibition, the seed must quickly repair these organelles to establish efficient aerobic respiration, which provides the high levels of ATP required for radicle protrusion and seedling growth.

55. (B) I and II
The glyoxylate cycle is essential for converting lipids into carbohydrates, utilizing the key enzymes isocitrate lyase and malate synthase. This pathway effectively bypasses the two decarboxylation steps of the citric acid cycle, preventing the loss of carbon as carbon dioxide. This conservation of carbon is critical for germinating seeds, as it allows for the net synthesis of glucose from acetyl-CoA via gluconeogenesis.

56. (D) β-amylase produces maltose from the non-reducing ends, while α-amylase acts internally
Beta-amylase is an exoenzyme that sequentially cleaves maltose units from the non-reducing ends of starch chains. In contrast, alpha-amylase is an endoenzyme that randomly hydrolyzes internal alpha-one-four glycosidic bonds, rapidly reducing the size of large starch polymers. Together, these enzymes work synergistically to break down starch granules into smaller, soluble sugars that can be easily utilized by the developing embryo during germination.

57. (B) Asparagine
Asparagine is widely recognized as the major transport compound for mobilized nitrogen in many germinating legume species. It is a highly stable amide with a high nitrogen-to-carbon ratio, making it an efficient vehicle for moving nitrogen from the cotyledons to the growing shoot and root tips. This transport ensures that the developing seedling has the necessary building blocks for synthesizing new proteins.

58. (C) They are continuously translocated to and utilized by the strong sink of the growing embryo
To ensure that mobilization continues efficiently, breakdown products such as sugars and amino acids must not accumulate to inhibitory levels in the storage tissues. These molecules are continuously translocated to the growing embryonic axis, which acts as a powerful metabolic sink. This constant removal maintains a concentration gradient that drives further mobilization, supporting the rapid growth and development of the new seedling.

59. (D) Scutellar epithelium
In cereal grains, the scutellar epithelium is the specialized layer of cells on the surface of the scutellum that faces the starchy endosperm. It serves as a structural and functional interface, separating the embryo from the storage tissue. During germination, these epithelial cells elongate and become highly active in secreting hydrolytic enzymes and absorbing the resulting breakdown products to nourish the embryonic axis.

60. (A) It synthesizes and secretes hydrolytic enzymes such as α-amylase
The aleurone layer responds to gibberellic acid originating from the embryo by initiating the synthesis and secretion of various hydrolytic enzymes. The most prominent of these is alpha-amylase, which breaks down the starch reserves in the endosperm. This response is a classic example of hormonal regulation in plants, where a signal from the embryo coordinates the mobilization of food reserves.

61. (B) Physical dormancy
Physical dormancy is explicitly caused by the presence of a hard, water-impermeable seed coat that prevents the entry of moisture into the seed. This type of dormancy is common in plant families such as Fabaceae and Malvaceae. To overcome physical dormancy, the seed coat must be breached through natural processes like temperature fluctuations or artificial methods like mechanical or chemical scarification.

62. (C) A is true but R is false.
Secondary dormancy is indeed an adaptive trait that prevents germination under temporarily unfavorable environmental conditions, ensuring that seeds only sprout when survival is likely. However, the claim that it only occurs in seeds lacking primary dormancy is false. Many seeds can transition from primary dormancy into a non-dormant state and then back into secondary dormancy if the right environmental triggers are present.

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producing smaller oligopeptides. This action increases the number of terminal ends available for exopeptidases, which then complete the breakdown into individual amino acids. This coordinated enzymatic process is essential for efficiently releasing the nitrogen reserves stored in the endosperm or cotyledons during the germination process.

81. (D) Nitrogen
In some legume species, particularly those of tropical origin, ureides such as allantoin and allantoic acid serve as the primary transport molecules for mobilized nitrogen. These compounds are produced from the breakdown of purines and have a high nitrogen-to-carbon ratio, making them efficient for translocation. They move from the storage tissues to the growing regions of the seedling, supporting the synthesis of new nitrogenous components.

82. (C) The cotyledons
In dicotyledonous seeds, the cotyledons are the structures that are functionally analogous to the scutellum of monocots in terms of reserve absorption. During germination, if the seed is albuminous, the cotyledons absorb nutrients from the endosperm. In exalbuminous seeds, the cotyledons already contain the stored reserves, but they still function to mobilize and transfer these nutrients to the growing root and shoot axes.

83. (B) GA-MYB mRNA
The de novo synthesis of alpha-amylase in the aleurone layer is triggered by gibberellic acid, which induces the prior synthesis of GA-MYB mRNA. Once the GA-MYB transcription factor is produced, it binds to the promoter regions of the alpha-amylase genes, initiating their transcription. This sequence of events represents a critical regulatory pathway that ensures the timely mobilization of starch reserves during the germination of cereal grains.

84. (D) Physiological dormancy
A seed that requires a period of cold, moist conditions to overcome dormancy is exhibiting physiological dormancy. This requirement, known as stratification, simulates the natural process of overwintering. During this period, biochemical changes occur within the seed, such as a shift in the balance of abscisic acid and gibberellins, which eventually allows the seed to germinate when warmer temperatures arrive.

85. (A) P-2, Q-4, R-3, S-1
Various treatments are used to break seed dormancy through different mechanisms. Mechanical scarification physically breaches an impermeable seed coat. Cold stratification satisfies the chilling requirement to alter the internal ABA to GA ratio. Thiourea application stimulates metabolic pathways to overcome specific physiological inhibitions. Finally, exogenous GA3 application directly substitutes for the lack of endogenous gibberellin synthesis required to trigger the germination process.

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86. (C) Abscisic Acid (ABA)
Abscisic acid is the primary hormonal antagonist to gibberellin in the regulation of seed dormancy and germination. While ABA promotes the establishment and maintenance of dormancy, gibberellins are essential for breaking dormancy and initiating the mobilization of reserves. The relative ratio of these two hormones acts as a molecular switch that determines whether a seed remains quiescent or begins to grow.

87. (A) It promotes germination by overcoming specific physiological blocks
The application of thiourea to certain dormant seeds promotes germination by helping to overcome specific physiological blocks. Although the exact mechanism can vary, it is often associated with the stimulation of the pentose phosphate pathway or the mitigation of inhibitory substances within the seed. This chemical treatment is a useful tool for increasing germination rates in species that exhibit deep physiological dormancy.

88. (D) Specific targeted mRNA transcripts are selectively degraded or synthesized via subtle hydration pockets
During the process of after-ripening in dry seeds, the transcriptome is not completely static. Instead, specific targeted mRNA transcripts are selectively degraded or synthesized, likely facilitated by subtle pockets of hydration within the seed matrices. These molecular changes gradually shift the seed's physiological state, reducing the influence of dormancy-promoting factors and preparing the embryo for germination once it is fully rehydrated.

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72. (A) II, IV, I, III
Lipid mobilization begins with the hydrolysis of triacylglycerols by lipases into fatty acids and glycerol. The fatty acids then undergo beta-oxidation in the glyoxysomes to produce acetyl-CoA. This is followed by the glyoxylate cycle, where acetyl-CoA is converted to succinate, then to malate and oxaloacetate. Finally, oxaloacetate is converted into sucrose through the process of gluconeogenesis in the cytosol.

73. (B) They lack desiccation tolerance and maintain high moisture, leading to membrane phase transitions
Recalcitrant seeds are highly susceptible to chilling injury because they lack desiccation tolerance and maintain a high moisture content throughout their development. At low temperatures, the water-rich membranes can undergo phase transitions from a liquid-crystalline to a solid-gel state. This transition disrupts membrane function and leads to irreparable cellular damage, explaining why these seeds cannot be stored in standard cold facilities.

74. (C) Sucrose
Sucrose is a crucial non-reducing sugar that contributes to the formation of a biological glass, or glassy state, during seed desiccation. In orthodox seeds, high concentrations of sucrose and certain oligosaccharides prevent the crystallization of cellular components as water is lost. This vitreous state significantly restricts molecular mobility, thereby stabilizing proteins and membranes and protecting the seed's viability during long-term dry storage.

75. (D) Reactive Oxygen Species (ROS) accumulation and oxidative stress
The physiological aging of seeds is fundamentally linked to the accumulation of reactive oxygen species and the resulting oxidative stress. Over time, these highly reactive molecules damage critical cellular components, including membranes, proteins, and DNA. This cumulative damage impairs the seed's metabolic efficiency and structural integrity, leading to reduced vigor, slower germination, and eventually the total loss of viability.

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76. (A) Mobilization of reserves and transcriptomic activation
During the lag phase of seed imbibition, metabolic activity is remarkably high despite minimal changes in total water content. This phase is characterized by the mobilization of internal reserves, the repair of cellular structures, and significant transcriptomic activation. These processes are essential for preparing the embryo for radicle protrusion, as the seed transitions from a quiescent state to an actively growing seedling.

77. (B) Oxidative phosphorylation linked to the TCA cycle
Once the radicle has emerged and oxygen becomes more available, the growing embryo generates most of its ATP through oxidative phosphorylation linked to the citric acid cycle. While early germination may rely on fermentation or pre-existing enzymes, the sustained growth of the seedling requires the highly efficient energy production provided by aerobic respiration within the newly repaired and biogenesis-derived mitochondria.

78. (C) I, III and IV
In seed metabolism, lipases are responsible for cleaving fatty acids from the glycerol backbone of triacylglycerols. Limit dextrinase is the specific enzyme that debranches starch by hydrolyzing alpha-one-six linkages. Exopeptidases facilitate protein mobilization by releasing single amino acids from the ends of peptide chains. Isocitrate lyase, however, is a key enzyme of the glyoxylate cycle, not glycolysis, making statement two incorrect.

79. (A) Maltose
The synergistic action of alpha and beta amylases in the endosperm primarily results in the accumulation of maltose. Alpha-amylase cleaves internal bonds to create smaller chains, while beta-amylase removes maltose units from the ends of these chains. This disaccharide is subsequently hydrolyzed by alpha-glucosidase into glucose, which provides the necessary energy and carbon for the growth of the embryonic axis.

80. (C) Hydrolyzing internal peptide bonds to produce oligopeptides
Endopeptidases facilitate protein mobilization by hydrolyzing internal peptide bonds within large storage protein molecules, thereby

98. (A) I, II, IV and V
Seed hydration follows a triphasic curve where Phase I is a physical process driven by matric potential. Phase II involves metabolic preparation with minimal volume change. Phase III coincides with radicle emergence and is driven by solute potential. Contrary to one statement, Phase III is a sign of successful germination in living seeds. These phases collectively describe the transition from a dry to a growing state.

99. (B) Pre-existing mitochondria that undergo structural repair
The resumption of respiration during the very early stages of Phase I germination relies on pre-existing mitochondria that were formed during seed development. Upon imbibition, these organelles undergo rapid structural repair and reactivation to begin providing energy. While new mitochondria are eventually synthesized during Phase II, the immediate metabolic response of the seed is driven by the restoration of these conserved cellular components.

100. (D) Isocitrate lyase
Isocitrate lyase is a key enzyme of the glyoxylate cycle, specifically catalyzing the cleavage of isocitrate into glyoxylate and succinate. This reaction is fundamental for the conversion of stored lipids into carbohydrates in germinating oilseeds. By bypassing the decarboxylation steps of the citric acid cycle, isocitrate lyase allows the seed to conserve carbon atoms for the eventual synthesis of glucose through gluconeogenesis.

101. (A) Amylopectin
Amylopectin is the highly branched component of starch, composed of glucose units linked by both alpha-one-four and alpha-one-six glycosidic bonds. These branch points occur approximately every twenty-four to thirty glucose residues, creating a complex, tree-like structure. Amylopectin typically makes up about seventy to eighty percent of the starch granule and is responsible for its semi-crystalline nature and many of its functional properties.

102. (B) They are translocated to the embryonic axis for new protein synthesis
The free amino acids generated by the action of peptidases in the endosperm or cotyledons are translocated to the growing embryonic axis. Once there, they are used as building blocks for the de novo synthesis of proteins required for the development of the new seedling. This mobilization of nitrogen reserves is a critical step in the transition from a dormant seed to an actively growing plant.

103. (D) Active transport mediated by sucrose-H^+ symporters
The movement of sucrose from the scutellum or cotyledons into the developing embryonic axis is primarily facilitated by active transport. Specialized membrane proteins, known as sucrose-H^+ symporters, use the proton motive force to move sucrose molecules against a concentration gradient. This active process ensures a steady supply of energy and carbon to the rapidly growing regions of the seedling, even when internal sugar levels are high.

104. (D) α-amylase
In barley seeds, the de novo synthesis of alpha-amylase in the aleurone layer is the classic physiological marker for a response to gibberellic acid. When the embryo releases GA, it diffuses to the aleurone layer and triggers the transcription of the alpha-amylase gene. The subsequent production and secretion of this enzyme into the endosperm are essential for the mobilization of starch reserves during germination.

105. (A) Both A and R are true and R is the correct explanation of A.
Gibberellic acid plays a central role in triggering the mobilization of endosperm reserves in cereal grains. It diffuses from the embryo to the aleurone layer, where it initiates a signaling cascade that results in the transcription of genes encoding various hydrolytic enzymes. Therefore, both the assertion regarding GA's role and the reason explaining its mechanism are true, with the reason directly explaining the assertion.

106. (B) An embryo that is undifferentiated or rudimentary at the time of seed dispersal
Morphological dormancy is characterized by seeds that possess an undifferentiated or rudimentary embryo at the time they are shed from the mother plant. Such embryos are not fully developed and must undergo further growth within the seed before germination can occur. This growth often requires specific environmental conditions, such as warm or cold periods, ensuring that the seed only sprouts when the season is favorable.

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89. (B) The presence of two cotyledons versus one
The fundamental anatomical difference between typical dicotyledonous and monocotyledonous seeds is the number of cotyledons in the embryo. Dicots, as the name suggests, possess two cotyledons, which often serve as major storage organs. Monocots possess a single cotyledon, which in many species is modified into a scutellum for nutrient absorption. This structural distinction is established early during the process of embryogenesis.

90. (C) It undergoes unequal transverse division to form an apical and a basal cell
In the early stages of embryogenesis, the zygote typically undergoes an unequal transverse division, resulting in a small apical cell and a larger basal cell. The apical cell eventually gives rise to the bulk of the embryo, while the basal cell develops into the suspensor, which anchors the embryo and facilitates nutrient transfer from the maternal tissues. This first division is a critical event.

91. (D) Transfer cells
Transfer cells are specialized cells characterized by extensive inward growths of the cell wall, which significantly increase the surface area of the plasma membrane. These cells are frequently found at the interface between maternal and filial tissues in developing seeds. Their primary function is to facilitate the efficient transport of assimilates from the apoplast into the seed tissues, supporting the rapid accumulation of reserves.

92. (A) Glutelins
Glutelins are a class of storage proteins defined by their solubility in dilute acids or alkalis. Along with prolamins, they constitute a major portion of the storage proteins in many cereal grains, most notably wheat and rice. In wheat, glutelins are known as glutenins and are responsible for the strength and elasticity of dough. These proteins are typically high in molecular weight and complex structure.

93. (B) The physical barrier created by oleosin proteins on their surface
The coalescence of oleosomes during seed desiccation is prevented by the presence of oleosin proteins on their surface. These proteins create a stable physical and electrostatic barrier that keeps individual oil bodies separate even when the cell loses most of its water. This structural stabilization ensures that the stored lipids remain accessible to lipases for rapid mobilization once the seed begins the germination process.

94. (B) Abscisic acid (ABA)
Abscisic acid is the primary plant hormone responsible for orchestrating the transition from the reserve accumulation phase to the maturation drying phase. It prevents precocious germination (vivipary) and induces the synthesis of protective proteins and sugars that allow the seed to survive severe desiccation. The peak in ABA concentration during late development is essential for the seed to achieve its final dormant and tolerant state.

95. (A) They can be dried to 10-12% moisture but are sensitive to freezing at low moisture
Intermediate seeds are characterized by their ability to tolerate partial desiccation, typically down to ten or twelve percent moisture, but they remain sensitive to freezing temperatures when in this dry state. This behavior contrasts with orthodox seeds, which can be dried further and stored at sub-zero temperatures, and recalcitrant seeds, which die if dried significantly. This unique physiology presents challenges for long-term conservation.

96. (C) Glassy (vitreous) state
During severe desiccation, the cytoplasm of orthodox seeds achieves a glassy or vitreous state due to high concentrations of non-reducing sugars like sucrose. This biophysical state is characterized by high viscosity and the absence of crystalline structures, which effectively halts all chemical reactions and prevents the denaturation of proteins. This vitrification is a key factor in the long-term survival of seeds in a desiccated condition.

97. (D) Ellis and Roberts viability equations
The loss of seed viability over time is mathematically modeled using the Ellis and Roberts viability equations. These equations relate the lifespan of a seed lot to its initial quality and the environmental conditions of storage, specifically temperature and moisture content. This modeling is essential for seed bank management, as it allows for the prediction of when a seed lot will need to be regenerated.

63. (A) High temperature stress during imbibition (thermo-dormancy)
High temperature stress during the imbibition of certain seeds can induce a state known as thermo-dormancy, which is a form of secondary dormancy. This process is driven by the upregulation of abscisic acid biosynthesis and the downregulation of gibberellin levels. By maintaining dormancy at high temperatures, the seed avoids germinating in conditions that might be lethal to the young seedling.

64. (C) To soften or erode a hard, impermeable seed coat
Chemical scarification using concentrated sulfuric acid is primarily intended to soften or erode a hard, water-impermeable seed coat. By partially breaking down the outer protective layers, this treatment allows water and gases to reach the embryo, thereby triggering the germination process. This method is particularly effective for seeds that exhibit physical dormancy and are otherwise unable to imbibe water.

65. (D) A time-dependent loss of dormancy during dry storage accompanied by biochemical shifts
Dry after-ripening is the process by which seeds gradually lose their primary dormancy while being stored in a dry state. This transition is not simply a passive wait but involves subtle biochemical and transcriptomic shifts within the seed tissues. As dormancy is lost, the seed's requirements for germination become less stringent, eventually allowing it to sprout when moisture and suitable temperatures are provided.

66. (C) To act as haustorial organs that absorb nutrients from the endosperm
In albuminous seeds, the cotyledons are typically thin and broad, and their primary role during early germination is to act as haustorial organs. They remain in close contact with the persistent endosperm, absorbing the nutrients that are released as the endosperm is enzymatically degraded. These nutrients are then translocated through the cotyledons to the growing embryonic axis to support seedling establishment.

67. (B) Distinctly elongated cotyledons and a well-defined embryonic axis
The torpedo stage of embryogenesis is uniquely identifiable by the significant elongation of the cotyledons and the primary embryonic axis. At this point, the embryo has moved beyond the heart stage and begins to fill more of the seed cavity. The distinct shape, resembling a torpedo, marks a phase of rapid cell expansion and the further differentiation of the basic tissue layers.

68. (D) They convert incoming sucrose into glucose and fructose to maintain a concentration gradient
Invertases play a vital role in source-sink dynamics by converting incoming sucrose into glucose and fructose within the apoplast or vacuoles of the sink tissue. This hydrolysis maintains a steep concentration gradient for sucrose, ensuring its continuous unloading from the phloem. By effectively lowering the local sucrose concentration, invertases facilitate the steady flow of carbohydrates into the developing seed to support reserve accumulation.

69. (A) Triacylglycerols
In oilseed crops like Brassica, the major energy storage form is triacylglycerols, which are stored within specialized organelles called oleosomes. These lipids provide a highly concentrated source of energy and carbon for the germinating seedling. During germination, the triacylglycerols are hydrolyzed by lipases into fatty acids and glycerol, which are then converted into sugars through the glyoxylate cycle and gluconeogenesis.

70. (C) Rough endoplasmic reticulum and vacuoles
Protein bodies are specialized storage organelles that typically form from either the rough endoplasmic reticulum or the vacuoles during seed maturation. Storage proteins are synthesized on the ribosomes of the rough endoplasmic reticulum and then transported into the lumen or directed to vacuoles for accumulation. Over time, these proteins aggregate and solidify, forming the dense matrix of the mature protein body.

71. (A) Rapid cell division and formation of the basic embryonic body plan
The histodifferentiation phase is the earliest stage of seed development, characterized by rapid cell division and the establishment of the basic embryonic body plan. During this period, the zygote undergoes a series of precise divisions to form the proembryo, globular, heart, and torpedo stages. This phase sets the architectural foundation for all subsequent growth and the accumulation of storage reserves.

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107. (D) Prevents vivipary and delays germination until conditions are likely favorable
Primary dormancy is an essential biological trait that prevents seeds from germinating prematurely while still on the mother plant, a condition known as vivipary. Furthermore, it ensures that germination is delayed until the seeds have been dispersed and environmental conditions are most likely to support the survival of the seedling. This adaptation increases the overall fitness and reproductive success of the plant species in diverse environments.

108. (B) Initiation of germination
The balance between abscisic acid and gibberellins acts as a molecular switch for seed germination. A sudden drop in the ABA to GA ratio, caused by either a decrease in ABA levels or an increase in GA synthesis and sensitivity, typically results in the initiation of germination. This shift allows the embryo to overcome dormancy and begin the metabolic processes required for radicle protrusion and subsequent growth.

109. (D) Overwintering under cool, moist conditions
Stratification is an artificial technique used to break the physiological dormancy of seeds by exposing them to cool, moist conditions for a specific period. This process simulates natural overwintering, which many temperate plant species require to ensure that their seeds do not germinate until spring. During stratification, the internal hormonal balance shifts, increasing the seed's readiness to grow when temperatures eventually begin to rise.

110. (D) By reducing the sensitivity of the embryo to ABA and increasing sensitivity to GA
Transcriptomic changes during the after-ripening of dry seeds alter physiology by significantly reducing the embryo's sensitivity to the inhibitory effects of abscisic acid. Simultaneously, these changes often increase the sensitivity to germination-promoting gibberellins. This dual shift in hormonal perception allows the seed to respond more effectively to favorable environmental cues, eventually leading to the loss of primary dormancy and the initiation of germination.

111. (B) Apomictic seed
An apomictic seed is one that develops without the process of fertilization but still maintains the standard structure and physiology of a typical seed. This form of asexual reproduction, known as apomixis, results in offspring that are genetically identical to the mother plant. Apomictic seeds are economically important in agriculture because they allow for the stable propagation of hybrid vigor through successive generations.

112. (B) Suspensor
In dicotyledonous embryogenesis, the first division of the zygote is typically unequal, producing a small apical cell and a large basal cell. The basal cell subsequently divides to form the suspensor, a structure that anchors the developing embryo to the maternal tissue and facilitates the transfer of nutrients. The suspensor also plays a role in signaling and coordinating early embryonic development before eventually regressing.

113. (D) There are no plasmodesmata connecting maternal tissue and embryonic tissue
Phloem unloading in the developing seeds of most plants must include an apoplastic step because there is no symplastic continuity between the maternal and filial generations. Maternal tissues and embryonic tissues are separate generations, and no plasmodesmata link their respective cytoplasms. Therefore, all nutrients, including sugars and amino acids, must be released into the apoplastic space before being actively taken up by the developing embryo.

114. (D) Lysine
Cereal endosperms are generally deficient in the essential amino acid lysine, a nutritional limitation that is closely related to their specific storage protein profile. The predominant proteins in many cereals are prolamins, which are characteristically low in lysine but high in proline and glutamine. This deficiency makes cereal-based diets incomplete for humans and livestock unless they are supplemented with other protein sources that provide lysine.

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115. (B) The radial orientation of amylopectin crystals
Starch granules exhibit a characteristic Maltese cross pattern when viewed under polarized light due to the radial orientation of amylopectin crystals within the granule. These semi-crystalline regions are formed by the precisely ordered arrangement of branched glucose chains. This birefringence is a hallmark of the organized internal structure of the starch granule

developing embryo before maturity. As a result, the cotyledons become enlarged and serve as the sole massive storage organs for the nutritional reserves required to support germination and the early growth of the seedling before it becomes photosynthetic.

134. (D) Protoderm
During the early globular stage of embryogenesis, the outer layer of cells differentiates into the protoderm. This specialized tissue layer is the precursor to the epidermis of the mature plant. The formation of the protoderm is one of the first signs of tissue-level organization in the developing embryo, occurring as the proembryo reaches a specific cell number and begins to establish its basic body plan.

135. (B) Seed abortion or significantly reduced seed size (shrunken seeds)
Silencing the cell wall invertase gene during seed filling results in seed abortion or significantly reduced seed size, often producing shrunken seeds. Cell wall invertase is essential for converting incoming sucrose into glucose and fructose in the apoplast, which maintains the concentration gradient necessary for continuous phloem unloading. Without this enzyme, the sink strength of the developing seed is severely compromised, leading to a lack of nutrients.

136. (A) Three fatty acids esterified to a glycerol backbone
The basic chemical structure of a triacylglycerol consists of three fatty acid chains esterified to a single glycerol backbone. These molecules are the predominant form of lipid storage in seeds, providing a dense and efficient source of energy. During germination, lipases break the ester bonds to release the fatty acids, which are then processed through beta-oxidation and the glyoxylate cycle to produce carbohydrates for growth.

137. (A) A lipid core surrounded by a phospholipid half-unit membrane coated with oleosins
An oleosome, or oil body, consists of a central triacylglycerol core surrounded by a unique phospholipid half-unit membrane. This membrane is coated with specialized proteins called oleosins, which provide structural stability and prevent the oil droplets from coalescing. This arrangement ensures that the lipids remain as small, discrete droplets, maximizing their surface area for enzymatic attack by lipases during the mobilization phase of seed germination.

138. (D) Physiological maturity (maximum dry weight)
The physiological onset of maturation drying is usually preceded by the seed reaching physiological maturity, which is the point at which it achieves its maximum dry weight. At this stage, the accumulation of storage reserves is complete, and the vascular connections with the mother plant are typically severed. Following this peak, the seed begins to lose water rapidly, transitioning into a quiescent state suitable for dispersal and survival.

139. (B) Coffea arabica (Coffee)
Coffea arabica is a classic example of a plant species that produces intermediate seeds. These seeds can tolerate some desiccation but are sensitive to extreme drying and freezing temperatures, which distinguishes them from orthodox seeds. This intermediate behavior makes the long-term conservation of coffee genetic resources particularly challenging, as they cannot be stored under the standard low-temperature and low-moisture conditions used in most seed banks.

140. (A) I, II and IV
Late Embryogenesis Abundant proteins are intrinsically disordered molecules that are synthesized in large quantities during the final stages of seed development. Upon desiccation, they fold into more structured conformations, which allows them to protect cellular proteins and membranes from damage. While they are crucial for tolerance, they do not promote crystallization; instead, they help form a stable biological glass, making statement three incorrect.

141. (D) Temperature and moisture content
The rate of seed aging during storage is exponentially increased by elevating both the temperature and the moisture content of the environment. These two factors accelerate the biochemical reactions that lead to deterioration, such as lipid peroxidation and protein denaturation. Maintaining seeds in a cool, dry state is therefore the most effective strategy for preserving their viability and vigor over long periods in genebanks and agricultural storage.

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initial degradation is necessary for subsequent processing by other peptidases, which eventually release the free amino acids required for growth.

125. (D) A functional root system to absorb exogenous soil nitrogen
The transport of amides and ureides to the growing seedling axis is essential because the emerging seedling initially lacks a functional root system capable of absorbing nitrogen from the soil. During the early stages of germination, the plant is entirely dependent on the nitrogen reserves stored within the seed. These transport molecules move nitrogen from the storage organs to the developing tissues, supporting protein synthesis.

126. (D) Phosphorus and mineral cations
In addition to its role in enzyme secretion, the aleurone layer of cereal grains serves as a major storage site for phytic acid, also known as phytin. Phytic acid is the primary storage form of phosphorus and also binds essential mineral cations like potassium, magnesium, and calcium. During germination, the enzyme phytase hydrolyzes these reserves, releasing the minerals to support the metabolic needs of the developing seedling.

127. (D) cGMP and Calcium (Ca^{2+})
In the gibberellin-induced signal transduction pathway within aleurone cells, cyclic GMP and calcium ions act as important secondary messengers. Following the perception of GA at the cell surface or within the cytoplasm, these molecules relay the signal to the nucleus, where they help to activate the transcription of hydrolytic enzyme genes. These signaling components are essential for coordinating the massive enzymatic response required for reserve mobilization.

128. (B) Endogenous chemical blocks within the embryo or enclosing tissues
Physiological dormancy is primarily driven by endogenous chemical blocks located within the embryo itself or in the tissues immediately surrounding it, such as the endosperm or seed coat. These blocks often involve a high ratio of abscisic acid to gibberellins, which prevents the embryo from expanding. This form of dormancy is typical in temperate species and is usually overcome by specific environmental cues like stratification.

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129. (D) Induced secondary dormancy
Thermoinhibition occurs when seeds are prevented from germinating because they are exposed to unseasonably high temperatures during imbibition. This is a classic example of induced secondary dormancy, where a previously non-dormant seed enters a dormant state as an adaptive response to unfavorable conditions. This mechanism prevents the seed from sprouting when the probability of seedling survival is low due to heat stress or drought.

130. (A) P-3, Q-2, R-4, S-1
Different seed components specialize in storing specific substances. The aleurone layer is rich in phytic acid and specific proteins. The scutellum serves as a site for lipid storage and certain vitamins. The starchy endosperm is the primary reservoir of starch in cereals. In legumes, the cotyledons are the main storage organs for globulin proteins. Matching these correctly reflects the functional compartmentalization of nutritional reserves.

131. (D) Rubbing seeds on abrasive paper (scarification)
Rubbing seeds on abrasive paper, a form of mechanical scarification, is an effective method for breaking physical dormancy caused by a hard seed coat. This process creates small fissures or thins the outer layers, allowing water and gases to enter the seed and reach the embryo. By overcoming the physical barrier, scarification triggers the imbibition process and allows the previously dormant seed to begin germinating.

132. (D) Alleviate dormancy by altering hormonal sensitivity
During the process of dry after-ripening, the gradual and controlled accumulation of reactive oxygen species acts as a positive signal to alleviate seed dormancy. These oxidative events can lead to the targeted modification of specific proteins and messenger RNAs involved in dormancy maintenance. Consequently, the seed's hormonal sensitivity is altered, typically decreasing the influence of abscisic acid and increasing the embryo's readiness to germinate.

133. (C) Fabaceae (Legumes)
The Fabaceae family, which includes legumes like beans, peas, and soybeans, typically produces exalbuminous seeds. In these species, the endosperm is almost entirely consumed by the

and reflects the high degree of molecular order required for its formation.

116. (A) Water and the accumulation of storage compounds
Cell expansion during the reserve accumulation phase of seed development is primarily driven by the massive influx of water and the synthesis of storage compounds. As starch, proteins, and lipids accumulate within the vacuoles and specialized plastids, the osmotic pressure and physical volume of the cells increase. This expansion accounts for most of the growth in seed size and weight following the initial histodifferentiation phase.

117. (D) They cannot survive drying to the low moisture contents necessary for sub-zero storage
Recalcitrant seeds are exceptionally difficult to store in standard genebanks because they cannot survive the drying process required for long-term sub-zero storage. Unlike orthodox seeds, which can be desiccated to five percent moisture, recalcitrant seeds lose viability if their moisture content falls below a high critical level. This sensitivity necessitates specialized conservation strategies, such as cryopreservation of excised embryos, to maintain their genetic diversity.

118. (D) Contributes to intracellular vitrification and stabilizes membranes
Sucrose is crucial during the later stages of orthodox seed maturation because it contributes to intracellular vitrification and stabilizes cellular membranes. By participating in the formation of a biological glass, sucrose prevents the crystallization of solutes as water is lost. This vitreous state significantly limits molecular movement, protecting proteins and lipids from damage and ensuring the seed remains viable during prolonged periods of severe desiccation.

119. (B) Formazan
The Tetrazolium test for seed viability relies on the biochemical reduction of colorless 2,3,5-triphenyl tetrazolium chloride to a red-colored, insoluble compound called formazan. This reaction is catalyzed by dehydrogenase enzymes in the respiratory chain of living cells. The presence of the red pigment in the embryonic tissues provides a visual confirmation that the seed is metabolically active and capable of respiring, thus indicating its viability.

120. (B) I and III
In the triphasic curve of seed water uptake, Phase I is a purely physical process driven by the matric potential of the dry seed tissues. Phase III coincides with radicle emergence and is characterized by a resumption of rapid water uptake. Phase II, contrary to the second statement, is a lag phase where water uptake is minimal and cell division has not yet become dominant.

121. (B) Alcohol dehydrogenase
The shift from anaerobic to aerobic respiration during the early stages of seed germination is marked by a sharp decline in the activity of alcohol dehydrogenase. In the initial phases of imbibition, oxygen availability may be limited, leading to a temporary reliance on fermentation. As the seed hydrates and mitochondrial function is restored, the aerobic pathways become dominant, and the enzymes of fermentation are downregulated.

122. (B) Acetyl-CoA
During the process of beta-oxidation in glyoxysomes, long-chain fatty acids are sequentially degraded into two-carbon units in the form of acetyl-CoA. These acetyl units then enter the glyoxylate cycle, where they are used to synthesize four-carbon dicarboxylic acids like succinate. This pathway is essential for germinating oilseeds, as it allows them to convert stored lipids into the sugars needed to fuel early seedling growth.

123. (D) α-glucosidase (maltase)
The complete breakdown of starch grains in cereal endosperms requires a suite of enzymes working in coordination. While alpha and beta amylases break down the starch into smaller dextrins and maltose, alpha-glucosidase is responsible for the final conversion of maltose into two free glucose molecules. This final step is crucial for providing the simple sugars that the embryonic axis uses for respiration and as building blocks.

124. (D) Acidic endopeptidases
Acidic endopeptidases are the primary proteases responsible for the initial processing of large, insoluble globulin complexes in many seeds, particularly legumes. These enzymes function optimally at low pH and cleave internal peptide bonds to break the massive storage proteins into smaller, more soluble fragments. This

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142. (D) Independent of the seed's viability
During Phase I of hydration, water uptake is a purely physical process driven by the matric potential of the dry seed tissues. Because it relies on the physical properties of cellular components like cell walls and storage proteins rather than active metabolism, it occurs regardless of whether the seed is alive or dead. This initial imbibition is the first step for any seed placed in a moist environment.

143. (D) The Oxidative Pentose Phosphate Pathway (OPPP)
The oxidative pentose phosphate pathway is the primary metabolic route for generating the reducing power, in the form of NADPH, required for biosynthetic reactions during early germination. In addition to providing NADPH, this pathway also produces ribose-five-phosphate, which is essential for the synthesis of new nucleic acids. The activation of the OPPP is one of the earliest metabolic shifts observed following the imbibition of the seed.

144. (D) PEP carboxykinase (PEPCK)
In germinating seeds, the enzyme phosphoenolpyruvate carboxykinase catalyzes the crucial step of converting oxaloacetate into phosphoenolpyruvate during gluconeogenesis. This reaction allows the carbon derived from stored lipids to enter the glycolytic pathway in reverse, eventually leading to the synthesis of sucrose. PEPCK is highly active in the tissues of oilseeds during the mobilization phase, providing the necessary sugar to support the growth of the seedling.

145. (A) The presence of α-1,6 branch points
Alpha-amylase is an endoenzyme that can only hydrolyze internal alpha-one-four glycosidic bonds within starch molecules. It cannot cleave the alpha-one-six branch points found in amylopectin, nor can it bypass them. Consequently, the action of alpha-amylase alone results in the formation of large, branched fragments called limit dextrins. Complete degradation of starch to glucose requires additional enzymes like limit dextrinase and alpha-glucosidase to handle these branches.

146. (D) Cysteine proteinases
Cysteine proteinases are a major class of proteolytic enzymes abundant in germinating seeds, characterized by having a specific cysteine residue at their active site. These enzymes are often responsible for the initial breakdown of massive storage proteins into smaller peptides. They are typically synthesized de novo in response to germination signals and are often localized in specialized vacuoles where they contribute to the efficient mobilization of nitrogen reserves.

147. (C) Loaded into the scutellum and converted back to transportable sucrose
To prevent localized osmotic stress that could damage cellular structures, the high concentrations of simple sugars generated in the endosperm are rapidly absorbed by the scutellum. Within the scutellar tissues, these sugars are typically converted back into sucrose. This sucrose is then loaded into the phloem and translocated to the rapidly growing regions of the embryonic axis, maintaining a steady flow of nutrients throughout the germination process.

148. (A) Both A and R are true and R is the correct explanation of A.
The scutellum of a germinating cereal grain undergoes significant morphological changes, including the elongation of its epithelial cells. These elongated cells form a haustorium-like interface that maximizes the surface area for the absorption of nutrients mobilized from the starchy endosperm. Therefore, both the assertion regarding the morphological changes and the reason explaining their absorptive function are true, with the reason providing a direct physiological explanation.

149. (D) By massively upregulating the transcription of specific α-amylase genes
The aleurone layer ensures the massive production of alpha-amylase by upregulating the transcription of specific genes in response to gibberellic acid. This process involves the degradation of repressor proteins and the subsequent binding of the GA-MYB transcription factor to the enzyme's promoter. This robust transcriptional response allows the aleurone cells to synthesize and secrete large quantities of the enzyme required to hydrolyze the starch stored in the endosperm.

150. (D) Apiaceae (Umbellifers)
Morphological dormancy is frequently observed in the Apiaceae family, which includes plants like carrots and celery. Seeds in this family often contain embryos that are very small or undifferentiated when they are dispersed. These

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embryos must undergo a period of growth and development within the seed coat after imbibition before they can successfully germinate. This mechanism ensures that germination is timed appropriately with favorable environmental conditions.

151. (A) High levels of endogenously synthesized ABA in the developing seed
High levels of endogenously synthesized abscisic acid during seed development are fundamentally responsible for initiating primary dormancy. This hormone prevents the embryo from germinating precociously while still on the mother plant and prepares it for the maturation drying phase. The accumulation of ABA ensures that the seed enters a dormant state, which must eventually be overcome by specific environmental or physiological triggers after dispersal.

152. (C) Low ABA / High GA
According to the hormonal balance theory, seed germination is regulated by the relative concentrations of abscisic acid and gibberellins. A state characterized by low ABA and high GA is considered germination-permissive. In this condition, the inhibitory effects of ABA are minimized, and the growth-promoting and reserve-mobilizing actions of GA are maximized, allowing the seed to overcome dormancy and successfully sprout when environmental conditions are favorable.

153. (D) Potassium nitrate (KNO3)
Potassium nitrate is a common nitrogenous compound used as an exogenous treatment to break seed dormancy and promote uniform germination. Its effectiveness is particularly notable in many weed and agricultural species, where it may interact with light signaling pathways or alter internal nitrogen metabolism. This treatment is often included in standard seed testing protocols to ensure that the maximum germination potential of a seed lot is achieved.

154. (B) 5-15%
After-ripening occurs most effectively when orthodox seeds are stored in a dry state with a moisture content typically ranging between five and fifteen percent. This moisture level is low enough to prevent premature germination and slow down deterioration, yet sufficient to allow for the subtle biochemical and transcriptomic changes required to lose dormancy. Within this range, seeds gradually transition from a dormant to a non-dormant state over time.

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155. (A) Albuminous seeds retain endosperm; exalbuminous seeds consume it during development
The primary distinction between albuminous and exalbuminous seeds lies in the persistence of the endosperm at maturity. Albuminous seeds retain a large, prominent endosperm that serves as the main food source during germination. In contrast, exalbuminous seeds consume the endosperm during their development, and the nutritional reserves are instead stored within the enlarged cotyledons. This difference reflects diverse strategies for resource allocation during the process of embryogenesis.

156. (D) Hypocotyl-radicle axis and cotyledons
In dicotyledonous embryogenesis, the transition from the heart stage to the torpedo stage is characterized by the directed expansion of the hypocotyl-radicle axis and the cotyledons. At this stage, the embryo undergoes rapid cell expansion and elongation, filling a larger portion of the seed cavity. This phase is essential for defining the final proportions of the mature embryo and for establishing the structural readiness required for eventual germination and growth.

157. (D) SUT (Sucrose Transporter) / SUC
The active uptake of sucrose from the apoplastic space into the developing cotyledons or endosperm is mediated by specialized sucrose transporters, often abbreviated as SUT or SUC. these proteins are essential for seed filling because they move sucrose against its concentration gradient, ensuring that the filial tissues accumulate sufficient reserves. The activity of these transporters is a key factor determining the final yield and quality of the seed.

158. (A) Globulins
The globulin fraction represents the major storage proteins in most legume seeds, including well-known examples like phaseolin in beans and legumin in peas. These proteins are characterized by their solubility in dilute salt solutions and are stored in specialized protein bodies. During germination, they are broken down by various proteases to provide the essential nitrogen and amino acids needed by the developing seedling for new growth.

159. (D) Granule-bound starch synthase (GBSS)
Granule-bound starch synthase is the specific enzyme complex responsible for initiating and extending the synthesis of the amylose polymer within the starch granule. Unlike soluble starch synthases, which are primarily involved in amylopectin synthesis, GBSS is localized within the granule matrix itself. Its activity is essential for producing the linear glucose chains that characterize the amylose component of starch in both cereal and legume seeds.

160. (A) I, II, III and V
During the reserve accumulation phase, cell division typically arrests while cell expansion dominates to accommodate the massive synthesis of proteins, lipids, and starch. The seed reaches its maximum fresh weight as water and nutrients flow into the developing tissues. Vascular connections remain functional throughout most of this phase to ensure a steady supply of assimilates, making the fourth statement incorrect while the others correctly describe the process.

161. (D) 30-70%
Recalcitrant seeds do not undergo a final maturation drying phase and are shed from the mother plant at a very high moisture content, typically ranging from thirty to seventy percent. Because they lack desiccation tolerance, any significant loss of water leads to a rapid decline in viability. This high moisture status means they remain metabolically active and often germinate quickly after dispersal if conditions are suitable.

162. (A) By forming a biological glass that severely restricts molecular mobility
The accumulation of non-reducing sugars like sucrose and certain oligosaccharides facilitates desiccation tolerance by forming a biological glass within the cytoplasm. This vitreous state is highly viscous and lacks a crystalline structure, which effectively restricts the mobility of molecules. By preventing the crystallization of solutes and the denaturation of proteins, the glassy state preserves the cellular architecture and viability of the seed during severe dehydration.

163. (A) High temperature and high relative humidity
The accelerated aging test for seed vigor involves subjecting seeds to a brief period of high temperature and high relative humidity. These stressful conditions mimic the natural aging process at a much faster rate. Following this treatment, a standard germination test is conducted; seeds with high vigor will maintain a high germination percentage, while low-vigor seeds will show a significant decline in their ability to sprout.

164. (D) Phase II (Lag phase)
During Phase II of seed hydration, the lag phase, the synthesis of new messenger RNA and proteins essential for radicle protrusion occurs. Although there is little external change in seed volume or water content, the internal metabolic machinery is highly active, repairing damage and preparing for the final stage of germination. This phase is a critical turning point where the seed commits to completing the process of radicle emergence.

165. (A) Resumption of massive water uptake primarily driven by solute potential
The entry into Phase III of germination, marked by the radicle penetrating the seed coat, leads to a resumption of massive water uptake. This stage is primarily driven by the solute potential of the rapidly growing embryonic tissues. Unlike Phase I, which is a physical process, this phase is linked to active cell expansion and growth, ensuring that the seedling can establish itself and begin to draw nutrients from its environment.

166. (C) Glyoxysomes
Beta-oxidation, the process of breaking down long-chain fatty acids into acetyl-CoA, is primarily localized within the glyoxysomes of germinating oilseeds. These specialized peroxisomes contain the necessary enzymes for both beta-oxidation and the glyoxylate cycle. This spatial organization allows for the efficient conversion of stored lipids into the four-carbon intermediates required for gluconeogenesis, which ultimately provides the sugars needed for the growth of the young seedling.

167. (D) Limit dextrinase (pullulanase)
Limit dextrinase is the enzyme responsible for hydrolyzing the alpha-one-six branch points in amylopectin, making it essential for the complete conversion of starch into fermentable sugars. In the industrial process of malting, it is often the rate-limiting step because it is less stable than other amylases. Without sufficient limit dextrinase activity, large branched dextrins remain, reducing the overall yield of simple sugars during the mashing process.

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the removal of DELLA proteins, subsequently binding to the promoter of the alpha-amylase gene to induce its expression.

216. (B) The embryo is undifferentiated or rudimentary and requires time to grow inside the imbibed seed before germination
Morphological dormancy is defined as a state where the seed contains an undifferentiated or rudimentary embryo at the time of dispersal. Such embryos are not fully developed and cannot germinate until they have undergone further growth within the imbibed seed. This process often takes several weeks or months and may require specific temperature conditions. This mechanism ensures that the seed only sprouts when the embryo has reached the size and complexity necessary for seedling survival.

217. (D) Secondary dormancy
Secondary dormancy is an acquired state of dormancy that develops in mature, non-dormant seeds after they have been exposed to unfavorable environmental conditions. This allows seeds in the soil to survive seasonal cycles and avoid germinating when conditions are temporarily unsuitable. Unlike primary dormancy, which is present from the time of seed dispersal, secondary dormancy is induced by the environment, helping the seed to time its eventual germination with the return of favorable growth conditions.

218. (A) Abscisic acid
The molecular mechanism underlying the release from seed dormancy often involves the degradation of abscisic acid signaling factors. ABA is the primary hormone responsible for maintaining dormancy. When environmental conditions trigger the breaking of dormancy, the seed typically increases its rate of ABA catabolism and decreases its sensitivity to the hormone. This shift, often combined with an increase in gibberellin levels, allows the embryo to overcome the chemical blocks that were preventing its growth and germination.

219. (D) An upregulation of GA biosynthesis and increased GA sensitivity
Cold stratification is highly effective at breaking physiological dormancy because it triggers an upregulation of gibberellin biosynthesis and a significant increase in GA sensitivity within the seed. At the same time, the levels of the dormancy-promoting hormone abscisic acid typically decline. This shift in the hormonal balance prepares the seed to germinate as soon as temperatures become favorable, ensuring that the seedling emerges during the spring when growth conditions are most likely to be optimal.

220. (D) Selective non-enzymatic oxidation of specific dormancy-related proteins
During the process of dry after-ripening, several biochemical changes occur, including the selective non-enzymatic oxidation of specific dormancy-related proteins and messenger RNAs. This controlled oxidative process happens over time in the desiccated state and is a key factor in the gradual loss of seed dormancy. These molecular modifications reduce the effectiveness of the factors that were maintaining dormancy, eventually allowing the seed to respond to germination signals and sprout once it is rehydrated.

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221. (B) Exalbuminous
Exalbuminous is the functional term used to describe seeds that rely exclusively on their cotyledons for reserve storage, having completely consumed the endosperm during their development. Common in many dicotyledonous families like the Fabaceae, these seeds store their proteins, lipids, and carbohydrates in the enlarged cotyledonary tissues. During germination, these reserves are mobilized to nourish the developing embryonic axis until the seedling can establish its own photosynthetic system and begin drawing nutrients from the soil.

222. (D) Globular stage
At the globular stage of seed embryogenesis, the basic tissue patterning of the future plant is fully established. During this phase, the embryo forms distinct layers that will eventually become the protoderm, ground meristem, and procambium. This spatial organization defines the fundamental architecture of the embryonic body and ensures that the different tissue systems are in their proper positions for subsequent growth and differentiation through the heart, torpedo, and mature stages of development.

223. (D) Pressure-driven flow based on Münch's hypothesis
The bulk flow of assimilates into the seed coat phloem is driven by pressure gradients, according to the principles of Münch's hypothesis. Sugars are actively loaded into the phloem at the source

176. (A) Targeted oxidation of specific dormancy-associated mRNAs and proteins
The loss of dormancy during dry after-ripening is strongly correlated with the targeted non-enzymatic oxidation of specific dormancy-associated messenger RNAs and proteins. This process occurs slowly over time in the dry state, likely within small hydration pockets in the seed tissues. These oxidative modifications alter the molecular landscape of the embryo, gradually reducing the influence of inhibitory factors and increasing the seed's readiness to germinate upon eventual rehydration.

177. (D) The nucellus
The term perisperm refers to a specialized seed storage tissue that is derived from the maternal nucellus rather than the endosperm. While most seeds rely on the endosperm or cotyledons for nutrients, some species, such as those in the Amaranthaceae family, maintain a persistent perisperm. This tissue provides the necessary energy and carbon for the germinating embryo, representing an alternative maternal strategy for supporting the development of the next generation.

178. (A) A peak in endogenous Abscisic Acid (ABA) and high osmotic potential
During seed development, viviparous germination of the immature embryo is prevented by a peak in endogenous abscisic acid and a high osmotic potential within the seed tissues. ABA inhibits the metabolic processes required for germination, while the high osmotic potential limits water availability for expansion. Together, these factors ensure that the seed enters a quiescent state and completes its maturation and desiccation phases before eventually being dispersed from the mother plant.

179. (A) Between the maternal nucellar projection and the endosperm
In cereal grains, a symplastic discontinuity is typically located at the interface between the maternal nucellar projection and the filial endosperm. Because there are no plasmodesmata connecting these two tissues, all assimilates must be released into the apoplast. This apoplastic step is essential for the regulated transport of nutrients, as it allows for the active uptake of sugars and amino acids by specialized transporters on the surface of the endosperm.

180. (D) Gliadins (Prolamins) and Glutenins (Glutelins)
Wheat gluten, the protein complex responsible for the unique elasticity and structure of dough, is primarily composed of two protein fractions: gliadins and glutenins. Gliadins are a type of prolamin that contributes to dough extensibility, while glutenins are glutelins that provide strength and elasticity. Together, these storage proteins form a network when mixed with water, making wheat a vital crop for the production of various breads and pasta products.

181. (A) Lipases and lipid droplets are spatially separated or lipases are kept inactive
During seed development, stored lipids are protected from premature degradation because the lipases are either kept in an inactive state or are spatially separated from the lipid droplets. This compartmentalization ensures that the energy-rich triacylglycerols remain intact until they are needed during the mobilization phase of germination. Once germination is triggered, lipases are activated and gain access to the oil bodies, initiating the release of fatty acids for energy production.

182. (A) Triacylglycerol hydrolysis → Beta-oxidation → Glyoxylate cycle → Gluconeogenesis
The mobilization of stored lipids follows a specific sequence starting with triacylglycerol hydrolysis by lipases to produce fatty acids and glycerol. These fatty acids then undergo beta-oxidation in the glyoxysomes to yield acetyl-CoA. Next, the glyoxylate cycle converts acetyl-CoA into succinate, which is subsequently used in the cytosol for gluconeogenesis. This integrated pathway allows the germinating seed to convert its lipid reserves into the sugars required for growth and development.

183. (B) Substantially larger size and lack of a severe maturation drying phase
Recalcitrant seeds are often characterized by their substantially larger size and the absence of a severe maturation drying phase compared to orthodox seeds. Because they do not dry out before shedding, they maintain a high moisture content and remain metabolically active. This large size often provides a greater amount of storage reserves, allowing the seed to germinate almost immediately after dispersal in the consistently moist environments where these species typically thrive.

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growing root and shoot axes to support early seedling growth.

200. (D) Hypophysis, a derivative of the suspensor
During seed embryogenesis, the root apical meristem is derived primarily from the hypophysis, which is the uppermost cell of the suspensor. After the first unequal division of the zygote, the basal cell gives rise to the suspensor. The hypophysis then undergoes a series of precise divisions to contribute to the formation of the radicle's meristematic core. This event highlights the important role of the suspensor in providing cellular material for the primary embryonic tissues.

201. (A) The lack of symplastic continuity (plasmodesmata) between maternal and filial generations
The lack of symplastic continuity between the maternal and filial generations in developing seeds necessitates specialized transfer mechanisms for assimilates. Because no plasmodesmata connect these two generations, all nutrients must be released into the apoplastic space and then actively taken up by the developing embryo or endosperm. This structural barrier ensures that the mother plant can regulate the flow of resources and allows the filial tissues to maintain an independent internal environment during development.

202. (C) Soluble in dilute acids and bases
According to the Osborne classification system, glutelins are the protein fraction characterized by being soluble in dilute acids or bases. They are generally insoluble in water, salt solutions, or aqueous alcohol. Glutelins are prominent storage proteins in cereals, such as the glutenins found in wheat and the glutelins in rice. These proteins are often very large and contribute significantly to the structural and nutritional properties of the grain.

203. (B) A long central hydrophobic domain that anchors into the lipid, with hydrophilic ends facing the cytosol
Oleosins are unique proteins that stabilize oil bodies in seeds by having a long central hydrophobic domain that anchors into the triacylglycerol core. Their hydrophilic N-terminal and C-terminal ends extend into the cytosol. This structural configuration prevents the coalescence of oil droplets by providing both physical and electrostatic repulsion. This protection is critical during seed desiccation, ensuring that lipid reserves remain as discrete, accessible droplets for mobilization once the germination process begins.

204. (A) Metabolic processes shut down completely, entering a state of suspended animation (quiescence)
During the maturation drying phase, the seed's metabolic rate drops dramatically as it loses water and enters a state of suspended animation known as quiescence. Most metabolic processes shut down to protect the cellular machinery from damage and to conserve energy. This state allows the seed to remain viable for long periods in the environment, waiting for favorable conditions. The transition into quiescence is orchestrated by high levels of abscisic acid and protective molecules.

205. (B) II, I, III, IV
Seed germination typically follows a chronological sequence beginning with rapid initial imbibition driven by matric forces. This is followed by a lag phase characterized by high metabolic activity and cellular repair, but with no volume increase. Next, the radicle emerges through the seed coat, marking the completion of the germination process. Finally, sustained rapid water uptake occurs, driven by the solute potential of the growing seedling tissues as they expand.

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206. (C) Non-reducing sugars (e.g., sucrose, trehalose)
Non-reducing sugars like sucrose and trehalose are the primary molecules that provide structural stabilization for cellular membranes during severe desiccation. These sugars replace the water molecules that normally form a hydration shell around membrane phospholipids, thereby preventing phase transitions and fusion. This protection ensures that the membrane integrity is maintained even in the dry state, allowing for the successful resumption of cellular functions once the seed is eventually rehydrated during germination.

207. (A) Electrical conductivity test of seed leachates
The electrical conductivity test is a simple and effective method for measuring the loss of membrane semi-permeability associated with accelerated seed aging. As membranes deteriorate, they become leaky, allowing electrolytes to escape into the surrounding water

192. (A) Both A and R are true and R is the correct explanation of A.
The aleurone layer of a mature cereal grain consists of living cells that are capable of active protein synthesis during germination. While the cells of the starchy endosperm undergo programmed cell death during maturation, the aleurone cells survive the drying phase and remain metabolically competent. This survival is essential because the aleurone layer must respond to hormonal signals from the embryo by synthesizing and secreting the enzymes needed to mobilize the endosperm's stored reserves.

193. (A) The 26S proteasome
In the gibberellin signaling pathway, the twenty-six-S proteasome is the cellular machinery directly responsible for the degradation of DELLA proteins. When GA is perceived, it triggers the polyubiquitination of these repressors, marking them for destruction by the proteasome. The removal of DELLA proteins is a critical regulatory step that allows the transcription of GA-responsive genes, thereby initiating the various physiological processes required for seed germination and reserve mobilization.

194. (B) The embryo has a low growth potential that cannot overcome the mechanical restraint of the tissues
Physiological dormancy is a state where the embryo is fully mature but lacks sufficient growth potential to overcome the mechanical restraint imposed by the surrounding tissues, such as the endosperm or seed coat. This form of dormancy is the most common type and is regulated by internal hormonal balances. It is typically overcome when environmental signals, like light or cold periods, trigger biochemical changes that increase the embryo's thrust or weaken the enclosing structures.

195. (A) Phytochrome
Phytochrome is the primary photoreceptor that controls germination in photoblastic seeds. It exists in two interconvertible forms: Pr, which absorbs red light, and Pfr, which absorbs far-red light. Exposure to red light shifts the phytochrome to the active Pfr form, which then triggers a signaling cascade that promotes gibberellin synthesis and leads to the breaking of dormancy. This mechanism ensures that small seeds only germinate when they are close to the soil surface.

196. (D) Induction and maintenance of primary dormancy
An increase in the ratio of abscisic acid to gibberellins during seed development is directly responsible for the induction and maintenance of primary dormancy. ABA prevents the embryo from germinating precociously and induces genes that prepare the seed for the final stages of maturation and desiccation. High levels of ABA ensure that the seed remains in a quiescent state, protecting it until it is dispersed and eventually encounters the conditions required to break dormancy.

197. (B) Morphophysiological dormancy
Mechanical scarification is generally an inappropriate treatment for morphophysiological dormancy, as this state involves an underdeveloped embryo that also requires physiological changes to germinate. While scarification can help seeds with a hard coat, it does not address the internal development needs of the embryo. To overcome this complex dormancy, seeds typically require specific temperature cycles, such as stratification, which allow for both embryo growth and the relief of internal chemical blocks.

198. (A) Decreased sensitivity to ABA and increased sensitivity to GA
After-ripening in dry seeds typically results in a physiological state characterized by decreased sensitivity to the inhibitory effects of abscisic acid and increased sensitivity to the growth-promoting actions of gibberellins. This shift in hormonal perception allows the seed to germinate more readily and across a wider range of environmental conditions. These biochemical changes are essential for the natural loss of primary dormancy that occurs during storage before the seeds eventually sprout in the field.

199. (D) It possesses broad, thin cotyledons that absorb reserves from a persistent endosperm during germination
Ricinus communis is a classic example of a dicotyledonous albuminous seed. It possesses a massive, persistent endosperm that contains the bulk of the nutritional reserves. The embryo has broad, thin cotyledons that are positioned in close contact with the endosperm. During germination, these cotyledons serve as specialized absorptive organs, taking up the mobilized nutrients from the endosperm and translocating them to the

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168. (D) Acidic cysteine and aspartic proteinases
The degradation of protein bodies during germination is often initiated by a drop in internal pH, which creates an optimal environment for the activity of acidic cysteine and aspartic proteinases. These enzymes are specialized for functioning in acidic conditions and are responsible for the initial breakdown of large storage proteins into smaller peptides. This proteolytic activity is essential for mobilizing nitrogen reserves to support the rapid growth of the seedling.

169. (A) Through newly differentiated phloem sieve elements in the embryonic axis
The massive flow of sucrose from the scutellum to the growing radicle and plumule occurs primarily through the newly differentiated phloem sieve elements in the embryonic axis. As germination progresses, the vascular system of the embryo matures, providing a specialized pathway for the long-distance transport of nutrients. This efficient translocation system ensures that the rapidly dividing cells in the meristems receive a constant supply of energy and carbon.

170. (D) High osmotic potential caused by excess accumulated sugars
The secretion of α-amylase from the aleurone layer is heavily repressed by high osmotic potential within the endosperm, typically caused by the accumulation of excess sugars like glucose and maltose. This feedback inhibition mechanism ensures that reserve mobilization is coordinated with the embryo's demand. When the growing embryonic axis uses up these sugars, the osmotic potential drops, allowing the aleurone to resume the synthesis and secretion of hydrolytic enzymes.

171. (B) By promoting the polyubiquitination and subsequent proteasomal degradation of DELLA
Gibberellin signaling removes the inhibition of germination by promoting the polyubiquitination and subsequent proteasomal degradation of DELLA proteins. When GA binds to its receptor, the complex interacts with an E3 ubiquitin ligase, which tags the DELLA repressors for destruction by the twenty-six-S proteasome. This removal of the DELLA proteins allows the transcription of GA-responsive genes, such as those for alpha-amylase, triggering the mobilization of stored reserves.

172. (D) The strophiole (or lens)
Seeds with physical dormancy often possess specialized structures like the strophiole, also known as the lens, which act as environmental water gaps. Initially, these structures are sealed, preventing water from entering the seed. However, environmental triggers such as temperature fluctuations can cause the strophiole to open or rupture. This allows for the controlled entry of water, initiating the imbibition process and eventually leading to the germination of the seed.

173. (B) Primary dormancy develops during seed maturation; secondary is induced after dispersal by adverse conditions
The distinguishing feature between primary and secondary dormancy is the timing and cause of their induction. Primary dormancy is established during seed development on the mother plant and is present at the time of dispersal. Secondary dormancy, however, is induced in mature, non-dormant seeds after they have been shed, typically as an adaptive response to unfavorable environmental conditions that would be detrimental to the survival of a germinating seedling.

174. (A) ABI3 (ABA Insensitive 3)
The transcription factor ABI3 is a central mediator of abscisic acid signaling, playing a critical role in maintaining seed dormancy and preventing precocious germination. It regulates the expression of many genes involved in maturation and desiccation tolerance. High levels of ABI3 ensure that the seed remains in a dormant state even when water is present, until specific signals or environmental conditions trigger its eventual degradation or inactivation.

NODIA

175. (A) P-4, Q-3, R-1, S-2
Different chemical agents break seed dormancy through distinct physiological actions. Gibberellic acid directly substitutes for the lack of endogenous hormone synthesis. Potassium nitrate often interacts with light signaling and alters nitrogen metabolism. Thiourea is known to stimulate the pentose phosphate pathway, helping to overcome physiological blocks. Finally, sulfuric acid is used to erode impermeable seed coats, physically removing the barrier to water entry and allowing for imbibition.

during imbibition. By measuring the conductivity of this leachate, researchers and seed producers can assess the degree of cellular damage and the overall vigor and viability of a seed lot without conducting a full germination test.

208. (A) The physical characteristics of the seed matrices becoming fully hydrated
The transition from Phase I to Phase II of seed water uptake is strictly governed by the physical characteristics of the seed matrices as they become fully hydrated. Once the hydration of cell walls, proteins, and other macromolecules is complete, the steep matric potential gradient that drives imbibition disappears. At this point, the seed enters the lag phase, where total water content remains relatively constant while internal metabolic processes prepare the embryo for eventual radicle protrusion.

209. (C) Adenylate Energy Charge (AEC)
The adenylate energy charge is a critical metabolic ratio that increases significantly within minutes of seed imbibition. This value reflects the relative amounts of ATP, ADP, and AMP in the cells, indicating the overall energy status of the tissue. A rapid rise in AEC shows that the seed has successfully reactivated its respiratory pathways and is beginning to generate the energy required for cellular repair and the initiation of the complex metabolic processes of germination.

210. (B) Phytase
Phytase is the enzyme primarily responsible for the mobilization of mineral reserves by hydrolyzing phytin stored in the aleurone layer or cotyledons. Phytin is the major reservoir of phosphorus in the seed and also contains bound minerals like potassium, magnesium, and calcium. By breaking down phytin, phytase releases these essential nutrients, making them available for the metabolic and biosynthetic needs of the rapidly developing seedling during the early stages of its growth.

211. (D) β-amylase
Beta-amylase is the specific carbohydrate-degrading enzyme that targets terminal alpha-one-four glycosidic bonds to release the disaccharide maltose. It acts as an exoenzyme, moving along the starch chain from the non-reducing ends. This action is essential for the rapid conversion of starch into a transportable and easily hydrolyzable sugar. The resulting maltose is then further broken down into glucose by other enzymes, providing the energy needed for the germination and growth of the embryo.

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212. (A) Swift translocation of free amino acids and amides to the growing seedling
To ensure that protein mobilization continues efficiently, the free amino acids and amides produced by peptidases must be swiftly translocated to the growing embryonic axis. This constant removal prevents the accumulation of these products in the storage tissues, which would otherwise lead to end-product inhibition of the proteolytic enzymes. By maintaining a high demand for nutrients in the growing regions, the seedling effectively coordinates the breakdown of its nitrogen reserves in the endosperm or cotyledons.

213. (C) Coleorhiza
During the germination of grass seeds, the coleorhiza is the first structure to emerge. It is a protective, sheath-like tissue that encloses the young radicle. Upon imbibition, the coleorhiza swells and pushes through the pericarp and testa, followed shortly by the emergence of the radicle itself. This structure provides mechanical protection and may also assist in water uptake, ensuring the successful establishment of the primary root system in the soil environment.

214. (B) The scutellum
In cereal grains, the scutellum plays a dual role by both synthesizing hydrolytic enzymes and acting as an absorptive haustorium. It secretes enzymes such as alpha-amylase and proteases into the starchy endosperm to break down stored reserves. Simultaneously, its specialized epithelial cells absorb the resulting sugars and amino acids, converting them into transportable forms and moving them to the developing embryonic axis. This dual functionality makes the scutellum central to the nutrient management of germinating monocots.

215. (A) P-1, Q-3, R-2, S-4
The gibberellin signaling pathway in seeds involves several key components with specific roles. GID1 is the soluble receptor that binds to gibberellin. DELLA proteins are repressors that inhibit the response to GA. The SCF complex mediates the polyubiquitination of these repressors, marking them for destruction. Finally, GA-MYB is a transcription factor that is synthesized after

184. (D) Oligosaccharides to water
The vitrification or glassy state formation in the cytoplasm of a desiccating seed depends primarily on the proper ratio of oligosaccharides to water. As water is lost, the concentration of sugars like sucrose and raffinose increases, eventually forming a highly viscous, non-crystalline solid. This biological glass stabilizes cellular components and restricts molecular movement, protecting the seed's proteins and membranes from denaturation and ensuring long-term survival in a highly desiccated state.

185. (A) Pale, patchy, or entirely absent staining in critical embryonic regions
In seeds that have significantly deteriorated or aged, the tetrazolium test typically produces pale, patchy, or entirely absent staining in critical regions of the embryo. This lack of uniform red color indicates that the dehydrogenase enzymes are no longer active, reflecting a loss of respiratory capacity and metabolic integrity. Such staining patterns are a clear visual indicator of low seed vigor and a high likelihood of failure during germination.

186. (D) Total water potential
For water imbibition to cease initially during Phase I, the total water potential of the seed must become less negative than the surrounding soil potential. At the start of the process, the dry seed has an extremely negative water potential, creating a steep gradient that drives rapid water uptake. As the tissues hydrate and the pressure potential increases, the total water potential eventually equilibrates with the environment, slowing the rate of imbibition.

187. (A) Generating heat and maintaining electron flux when cytochrome c oxidase is limited or inhibited
The cyanide-resistant alternative oxidase pathway plays a significant role in seed respiration during early germination. Its primary function is to maintain electron flux and prevent the over-reduction of the respiratory chain when the standard cytochrome c oxidase pathway is limited or inhibited. This pathway also generates heat, which may assist in the mobilization of reserves or metabolic processes. It serves as an important alternative route for energy management during the critical hydration phase.

188. (C) Succinate
In the pathway for converting lipids to carbohydrates, succinate is the specific transport metabolite that crosses from the glyoxysome into the cytosol. It is produced by the glyoxylate cycle from two units of acetyl-CoA. Once in the cytosol, succinate is converted into malate and then oxaloacetate, which serves as the substrate for gluconeogenesis. This movement of carbon between organelles is essential for the efficient production of sucrose in germinating oilseeds.

189. (A) It cleaves maltose units strictly from the non-reducing ends of starch chains
Beta-amylase is defined as an exoenzyme because it strictly cleaves maltose units from the non-reducing ends of starch chains. It cannot hydrolyze internal glycosidic bonds, nor can it bypass the branch points in amylopectin. Its action is complementary to that of alpha-amylase, which breaks down large starch polymers into smaller pieces, thereby increasing the number of non-reducing ends available for beta-amylase to act upon during the mobilization of carbohydrate reserves.

190. (A) By assimilating it into amides like glutamine via glutamine synthetase
The germinating seed detoxifies and transports the ammonium ions generated during protein mobilization by assimilating them into amides like glutamine. This process is catalyzed by the enzyme glutamine synthetase. Amides are non-toxic and have a high nitrogen-to-carbon ratio, making them ideal for moving nitrogen through the phloem to the growing embryonic axis. This ensures that the seedling has a steady supply of nitrogen for the synthesis of new proteins and nucleic acids.

191. (A) Sink for simple sugars from the endosperm, and subsequently a source for the embryonic axis
During the mobilization and transport of reserves in cereal grains, the scutellum acts first as a strong sink for the simple sugars released from the endosperm. Once absorbed, these sugars are converted into sucrose within the scutellar tissues. The scutellum then functions as a source, actively translocating the sucrose to the rapidly growing embryonic axis. This dual role is essential for efficiently supplying the developing seedling with the energy it needs to grow.

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tissues, lowering the water potential and causing water to enter, which generates high hydrostatic pressure. This pressure then drives the movement of the phloem sap toward the sink, such as the developing seed, where the solutes are unloaded into the tissues to support reserve accumulation.

224. (A) Globulins
Globulins are the class of storage proteins that typically dominate in standard dicotyledonous seeds, such as those of soybeans, peas, and other legumes. Characterized by their solubility in dilute saline solutions, they provide a major source of nitrogen for the germinating seedling. These proteins are synthesized during the reserve accumulation phase and are stored in protein bodies. During germination, they are rapidly mobilized by proteases to supply the amino acids required for the development of new seedling tissues.

225. (A) A highly structured, ordered crystal lattice or an amorphous matrix, often containing inclusions of phytin
The ultrastructural configuration of storage proteins within a protein body can range from a highly structured, ordered crystal lattice to a more amorphous matrix. These bodies often contain specialized inclusions, such as globoids, which are rich in phytin and mineral cations. This organized compartmentalization ensures that the nitrogen and mineral reserves are densely packed and protected until they are needed during the mobilization phase, where they are enzymatically broken down to support the growing embryonic axis.

226. (A) Disconnection of the vascular supply (funiculus abscission)
The transition from the reserve accumulation phase to maturation drying is primarily marked by the disconnection of the vascular supply, a process often referred to as funiculus abscission. This event severs the flow of water and assimilates from the mother plant to the seed, signalling the end of its active growth phase. Following this disconnection, the seed loses water rapidly, its metabolic rate drops, and it achieves its final physiological state in preparation for dispersal and survival.

227. (B) 5-15%
Orthodox seeds undergo intense maturation drying, often reaching a final moisture content as low as five to fifteen percent. This severe desiccation is possible because these seeds have developed tolerance mechanisms, including the accumulation of protective sugars and proteins. This low moisture state is essential for the long-term survival of the seed, as it significantly reduces metabolic activity and prevents the development of fungal pathogens, allowing the seeds to be stored for extended periods in dry conditions.

NODIA

228. (D) LEA proteins
Late Embryogenesis Abundant proteins are a group of molecules heavily synthesized during the late stages of seed maturation. They act as molecular shields or chaperones, preventing the denaturation and aggregation of cellular proteins during severe water loss. By stabilizing cellular structures and contributing to the formation of a biological glass, LEA proteins ensure that the seed remains viable and its cellular components remain functional throughout the dry state, allowing for successful germination upon eventual rehydration.

229. (B) Polyunsaturated fatty acids in cellular membranes
During the process of seed aging, reactive oxygen species primarily target the polyunsaturated fatty acids found in cellular membranes, leading to lipid peroxidation. This oxidative damage disrupts the integrity and semi-permeability of the membranes, which causes increased solute leakage and impaired organelle function upon imbibition. This progressive degradation of the membrane system is a major factor contributing to the decline in seed vigor and the eventual loss of viability in stored seeds.

230. (B) Remains relatively constant while active metabolism and repair occur
During the typical Phase II of the seed hydration curve, the fresh weight of the seed remains relatively constant. Although there is no significant external uptake of water, this stage is characterized by intense internal metabolic activity. The seed repair damaged DNA and proteins, activates pre-existing enzymes, and initiates the mobilization of stored reserves. This preparation is essential for the transition to Phase III, which is marked by radicle emergence and a resumption of rapid water uptake.

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of which transcription factor family, promoting adult traits?
(A) KNOX
(B) MYB
(C) SPL (Squamosa Promoter Binding Protein-Like)
(D) WRKY

2024

18. Consider the following developmental phases in a typical angiosperm life cycle and identify their correct chronological sequence.
I. Vegetative mature phase
II. Embryogenesis
III. Reproductive phase
IV. Juvenile vegetative phase
(A) II, IV, I, III
(B) IV, II, I, III
(C) II, I, IV, III
(D) I, IV, II, III

2004

19. What role does gibberellic acid (GA) play in the phase transition of many woody angiosperms?
(A) GA is a universal inhibitor of the juvenile-to-adult transition.
(B) GA directly degrades miR172 in the shoot apex.
(C) GA application promotes the production of adventitious roots in all species.
(D) GA applications can induce phase reversion from adult back to juvenile.

2004

20. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R). Select the correct option.
Assertion (A): The juvenile phase is characterized by a high potential for adventitious root formation.
Reason (R): High endogenous auxin levels and lower concentrations of rooting inhibitors are typical of juvenile tissues.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2002

21. Which evolutionary strategy defines a semelparous plant?
(A) Reproducing multiple times throughout a prolonged lifespan.
(B) Alternating between sexual and asexual reproduction seasonally.
(C) Reproducing only once before naturally senescing and dying.
(D) Producing seeds continuously without undergoing senescence.

2012

22. Which term is synonymous with a plant life strategy where the individual flowers multiple times over successive years?
(A) Iteroparous
(B) Monocarpic
(C) Ephemeral
(D) Cleistogamous

2010

23. Agave americana typically grows vegetatively for decades, produces a massive inflorescence once, and then dies. This life cycle is classified as:
(A) Polycarpic perennial
(B) Iteroparous biennial
(C) Semelparous annual
(D) Monocarpic perennial

2004

24. What is the primary physiological trigger for whole-plant senescence in monocarpic plants post-flowering?
(A) Exhaustion of soil nutrients surrounding the local root zone.
(B) Hormone-regulated nutrient mobilization from vegetative tissues to developing seeds.
(C) Exposure to extreme cold temperatures during the stage of seed set.
(D) Photoperiodic shifts directly degrading chloroplasts in root systems.

2022

25. Identify the correct combination of statements regarding reproductive strategies.
I. Iteroparous plants invest heavily in survival and maintenance tissues.
II. Monocarpic plants always complete their life cycle within one year.
III. Removal of developing flowers or fruits can often delay senescence in monocarpic plants.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I

2025

26. In an unpredictable environment with high adult mortality but favorable conditions for

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(A) Early angiosperm pollen was predominantly monosulcate in its structural orientation.
(B) Tricolpate pollen is a defining synapomorphy used to identify the eudicot clade.
(C) The earliest angiosperm pollen lacked complex exine ornamentation.
(D) Pollen morphological diversification closely parallels macrofossil radiation events.

2010

10. Match the items in List I with those in List II.
List I: (Evolutionary concept or taxon)
P. Amborella trichopoda
Q. Bennettitales
R. Syncarpy
S. Triploid endosperm
List II: (Characteristic)
1. Fused carpels enhancing pollen tube competition
2. Basal angiosperm lacking vessels
3. Extinct lineage with flower-like reproductive structures
4. Product of double fertilization in most angiosperms
(A) P-2, Q-3, R-1, S-4
(B) P-3, Q-2, R-4, S-1
(C) P-1, Q-4, R-2, S-3
(D) P-2, Q-1, R-3, S-4

2025

11. The transition from the juvenile to the adult vegetative phase in plants is defined by which of the following biological shifts?
(A) A transition in leaf morphology, phyllotaxy, and rooting ability.
(B) The sudden and rapid onset of flower primordia initiation events.
(C) The immediate and total cessation of all primary meristematic activity.
(D) The rapid and systemic degradation of all chlorophyll in mature leaves.

2014

12. Which statement accurately differentiates vegetative maturity from reproductive competence?
(A) Vegetative maturity marks the physiological end of life, whereas reproductive competence starts at germination.
(B) Vegetative maturity is the acquisition of adult traits; reproductive competence is readiness to respond to floral signals.
(C) Reproductive competence occurs only in the juvenile phase before the stage of vegetative maturity is reached.
(D) Both terms describe identical physiological states in the growth cycles of woody perennials.

NODIA

2001

13. Which of the following is a classic morphological marker of juvenility in English ivy (Hedera helix)?
(A) Entire, ovate leaves and strictly orthotropic growth.
(B) Palmate, lobed leaves and plagiotropic (creeping) growth.
(C) Inability to form adventitious roots on healthy stem tissue.
(D) Spontaneous formation of terminal inflorescences on new stems.

2007

14. Grafting a mature flowering scion onto a juvenile rootstock generally results in which physiological outcome?
(A) The scion retains its reproductive competence and can flower.
(B) The scion permanently reverts to a juvenile non-flowering state.
(C) The rootstock immediately initiates its own floral organs.
(D) The plant undergoes immediate programmed cell death.

2013

15. The delayed onset of reproductive competence in forest trees is ecologically advantageous primarily because it:
(A) Prevents potential cross-pollination with smaller, herbaceous understory plants.
(B) Ensures that viable seeds are only produced during the coolest months of the year.
(C) Allows for biomass accumulation and canopy dominance before energy allocation to reproduction.
(D) Stops the extensive root systems from competing with symbiotic soil fungi.

2023

16. In many plant species, phase change from juvenile to adult is tightly regulated by the sequential action of which two microRNAs?
(A) miR399 and miR159
(B) miR165 and miR166
(C) miR390 and miR393
(D) miR156 and miR172

2024

17. The decrease in levels of miR156 during plant development leads directly to the up-regulation

(C) I and IV
(D) II and III

2003

36. During the transition to flowering, an increase in the concentration of which signaling molecule acts as a critical secondary messenger in the meristem?
(A) Calcium ions ($Ca^{\{2+\}}$)
(B) Sodium ions (Na^{+})
(C) Gaseous nitrogen
(D) Sulfuric acid

2004

37. Which technique is most appropriately used to visualize the spatiotemporal expression of floral meristem identity genes at the histological level?
(A) Atomic force microscopy
(B) Gas chromatography
(C) Bomb calorimetry
(D) In situ hybridization

2021

38. The transition from juvenility to flowering is often marked by changes in the methylation status of DNA. Typically, the activation of floral genes is associated with:
(A) Global hypermethylation of the entire genome.
(B) Targeted demethylation of specific floral promoter regions.
(C) Complete removal of all histones from the nucleus.
(D) Conversion of all cytosine residues to uracil.

2015

39. At the biochemical level, a high ratio of which two compounds was classically thought to favor flowering (the Klebs hypothesis)?
(A) Water / Carbon
(B) Oxygen / Hydrogen
(C) Carbon / Nitrogen
(D) Potassium / Phosphorus

2013

40. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R). Select the correct option.
Assertion (A): The shoot apical meristem expands and becomes domed during floral evocation.
Reason (R): Floral evocation involves a synchronization of cell divisions and an expansion of the central zone to accommodate floral organ primordia.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2001

41. Photoperiodism in plants is defined as the physiological response to:
(A) The absolute intensity of incident light.
(B) The angle of the sun relative to the horizon.
(C) The relative lengths of day and night.
(D) The spectral composition of light independent of duration.

2013

42. A short-day plant (SDP) will only flower when:
(A) The photoperiod exceeds a critical maximum duration.
(B) The continuous dark period exceeds a critical minimum duration.
(C) The continuous dark period is shorter than a critical duration.
(D) It is exposed to alternating 1-hour pulses of light and dark.

2017

43. Which ecological scenario best explains why a plant would evolve a long-day (LDP) photoperiodic requirement?
(A) To ensure flowering occurs before the onset of winter frost in temperate zones.
(B) To restrict flowering to the equatorial tropics where days are always short.
(C) To prevent flowering altogether when pollinators are abundant.
(D) To ensure flowering occurs during the increasing day lengths of spring or early summer.

2010

44. Day-neutral plants (DNPs) are characterized by their ability to flower:
(A) Regardless of the photoperiod, depending primarily on developmental age or biomass.
(B) Only under continuous 24-hour illumination.
(C) Only when days and nights are exactly 12 hours long.
(D) Exclusively in absolute darkness.

2017

45. What is the effect of a brief flash of red light during the middle of the dark period on a strict short-day plant?
(A) It induces precocious flowering.
(B) It has no physiological effect.

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seed germination, which reproductive strategy is theoretically most favored?
(A) Iteroparity
(B) Polycarpy
(C) Vivipary
(D) Semelparity

2017

27. How do perennial polycarpic plants prevent whole-plant senescence after reproduction?
(A) By maintaining a population of active vegetative meristems that do not convert to floral meristems.
(B) By completely halting all photosynthetic activity during fruit ripening.
(C) By shedding their root system annually.
(D) By synthesizing lethal amounts of ethylene in the vascular cambium.

2010

28. Which hormone is most strongly associated with delaying monocarpic senescence when applied exogenously to leaves?
(A) Abscisic acid
(B) Cytokinin
(C) Ethylene
(D) Jasmonic acid

2011

29. Select the INCORRECT statement concerning iteroparity.
(A) Iteroparous plants balance resource allocation between current reproduction and future survival.
(B) Iteroparous species are limited to annual and biennial growth habits.
(C) Forest trees are classic examples of iteroparous organisms.
(D) Iteroparity is generally advantageous in stable environments with high juvenile mortality.

2001

30. Which pair of terms correctly contrasts identical life strategy concepts?
(A) Iteroparous – Polycarpic
(B) Monocarpic – Iteroparous
(C) Semelparous – Polycarpic
(D) Semelparous – Monocarpic

2019

31. The sudden accumulation of carbohydrates in the apical meristem immediately preceding floral evocation is primarily attributed to:
(A) Increased localized photosynthetic rates in the meristematic dome.
(B) Breakdown of structural cellulose in the stem.
(C) Mobilization and transport of sucrose from mature source leaves.
(D) Enhanced absorption of carbon dioxide by roots.

2012

32. Which specific metabolic pathway is significantly up-regulated in the apical meristem during the transition to flowering to support rapid cell division?
(A) Photorespiration
(B) Lignin biosynthesis
(C) Fermentation
(D) Pentose phosphate pathway

NODIA

2021

33. The concept of "floral evocation" specifically refers to:
(A) The opening of the mature flower buds.
(B) The synthesis of anthocyanins in petal tissues.
(C) The release of pollen from the anthers.
(D) The irreversible commitment of the apical meristem to form floral primordia.

2022

34. What histological change is typically observed first in the shoot apical meristem during the transition from vegetative to reproductive growth?
(A) A surge in mitotic activity in the central zone, altering the tunica-corpus zonation.
(B) An increase in the central zone cell vacuolization.
(C) Complete lignification of the rib meristem.
(D) Shedding of the outermost tunica layer.

2014

35. Identify the INCORRECT combination of statements regarding biochemical markers of floral transition.
I. RNA synthesis sharply decreases in the meristem during evocation.
II. Protein synthesis inhibitors can block the transition to flowering.
III. An increase in ATP levels is observed in the meristem during transition.
IV. The mitotic index of the meristem decreases prior to floral initiation.
Which of the above statement(s) is/are INCORRECT?
(A) I and II
(B) III and IV

(B) Mitochondrion
(C) Nucleus
(D) Vacuole

2016

57. Identify the correct combination of statements regarding phytochrome types.
I. Phytochrome A (phyA) is light-labile and rapidly degrades in the Pfr form.
II. Phytochrome B (phyB) is light-stable and primarily mediates shade avoidance.
III. Both phyA and phyB mediate High Irradiance Responses (HIR) under identical wavelengths.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) II

2017

58. The shade avoidance syndrome in sun-adapted plants is triggered primarily by:
(A) A low Red to Far-Red (R:FR) ratio.
(B) A high Red to Far-Red (R:FR) ratio.
(C) Total darkness.
(D) High intensity blue light.

2015

59. Which domain of the phytochrome apoprotein is essential for autophosphorylation and kinase activity?
(A) PAS domain
(B) GAF domain
(C) PHY domain
(D) Histidine kinase-related domain (HKRD)

2015

60. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R). Select the correct option.
Assertion (A): Seeds requiring light for germination exhibit a Very Low Fluence Response (VLFR) that cannot be reversed by far-red light.
Reason (R): VLFR requires such a minute conversion of Pr to Pfr that even far-red light establishes a sufficient Pfr baseline to trigger germination.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2007

61. Cryptochromes are blue/UV-A light receptors that primarily regulate which of the following physiological processes?
(A) Phototropism and chloroplast accumulation
(B) Hypocotyl elongation inhibition and photoperiodic flowering
(C) Stomatal closure in the dark
(D) Root nodulation in legumes

2008

62. Which chromophores are non-cally bound to plant cryptochromes to facilitate light absorption?
(A) FAD and MTHF (pterin)
(B) Phytochromobilin and heme
(C) Retinal and beta-carotene
(D) Chlorophyll a and b

2024

63. Phototropins differ from cryptochromes in their function. Phototropins specifically mediate:
(A) Circadian clock entrainment
(B) Floral evocation
(C) Phototropism, chloroplast movement, and stomatal opening
(D) Seed germination in the dark

2004

64. The light-sensing domains characteristic of phototropins are known as:
(A) LOV (Light, Oxygen, Voltage) domains
(B) PAS domains
(C) CCT domains
(D) EAR motifs

2009

65. Identify the INCORRECT statement regarding the ZEITLUPE (ZTL) family of photoreceptors.
(A) They perceive blue light via a LOV domain.
(B) They possess an F-box domain linking them to ubiquitination.
(C) They are the primary receptors for red-light induced seed germination.
(D) They regulate the targeted degradation of circadian clock proteins.

2021

66. How does the activation of cryptochrome (CRY) promote photomorphogenesis at the molecular level?
(A) By binding to and inhibiting COP1, preventing the degradation of HY5.
(B) By directly degrading phytochrome Pfr.
(C) By phosphorylating phototropin.
(D) By synthesizing abscisic acid.

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(C) It inhibits flowering by breaking the critical dark period.
(D) It kills the apical meristem.

2009

46. Intermediate-day plants are a rare category that require:
(A) Alternating weeks of continuous light and continuous dark.
(B) Extremely short days followed immediately by freezing temperatures.
(C) Both long days and complete submersion in liquid water.
(D) Photoperiods between a specific minimum and maximum length to flower.

2017

47. Which plant species is classically studied as a model obligate short-day plant?
(A) Pharbitis nil (Japanese morning glory)
(B) Arabidopsis thaliana
(C) Hyoscyamus niger
(D) Spinacia oleracea (Spinach)

2023

48. If a long-day plant with a critical day length of 14 hours is exposed to 13 hours of light and 11 hours of darkness, the plant will:
(A) Flower profusely.
(B) Remain vegetative.
(C) Form tubers instead of flowers.
(D) Undergo immediate leaf abscission.

2022

49. The site of photoperiodic perception in higher plants is primarily the:
(A) Shoot apical meristem
(B) Root tip
(C) Mature leaf blade
(D) Floral primordia

2005

50. Match the items in List I with those in List II.
List I: (Photoperiodic classification)
P. Short-day plant (SDP)
Q. Long-day plant (LDP)
R. Day-neutral plant (DNP)
S. Long-short-day plant (LSDP)
List II: (Flowering requirement)
1. Flowers regardless of day length
2. Requires long days followed by short days
3. Flowers when the dark period exceeds a critical length
4. Flowers when the day length exceeds a critical length
(A) P-3, Q-4, R-1, S-2
(B) P-4, Q-3, R-2, S-1
(C) P-3, Q-1, R-4, S-2
(D) P-1, Q-4, R-3, S-2

2024

51. Phytochromes act as reversible biological switches. The biologically active form that initiates photomorphogenic responses is predominantly:
(A) Pr, which absorbs red light.
(B) Pr, which absorbs far-red light.
(C) Pfr, which absorbs blue light.
(D) Pfr, which absorbs far-red light.

2012

52. What is the peak absorption wavelength for the Pr form of phytochrome?
(A) 450 nm
(B) 660 nm
(C) 730 nm
(D) 850 nm

2023

53. The chromophore responsible for light absorption in plant phytochromes is an open-chain tetrapyrrole known as:
(A) Phytochromobilin
(B) Beta-carotene
(C) Flavine adenine dinucleotide
(D) Chlorophyll a

2001

54. Which phytochrome response is characterized by being fully reversible by far-red light and obeys the law of reciprocity?
(A) Low Fluence Response (LFR)
(B) Very Low Fluence Response (VLFR)
(C) High Irradiance Response (HIR)
(D) Gravitropic Response (GR)

2010

55. High Irradiance Responses (HIR) mediated by phytochrome differ from Low Fluence Responses (LFR) because HIR:
(A) Requires brief, low-intensity flashes of light.
(B) Is fully reversible by far-red light.
(C) Depends on the continuous presence of light and irradiance level.
(D) Operates exclusively in the root system.

2012

56. Upon conversion to the active Pfr form, phytochrome typically translocates from the cytosol into which cellular compartment to regulate gene expression?
(A) Chloroplast

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2019

77. Which environmental signal is the most potent zeitgeber (time-giver) for entraining the plant circadian clock?
(A) Soil moisture fluctuations
(B) Wind velocity
(C) Atmospheric pressure changes
(D) Light/dark transitions

2025

78. If an Arabidopsis plant is moved from entrained light/dark cycles into continuous darkness, its leaf movement rhythm will:
(A) Stop immediately.
(B) Continue to oscillate for several days with a period of roughly 24 hours.
(C) Continue with a period of exactly 12 hours.
(D) Accelerate until leaves abscise.

2011

79. The PRR (Pseudo-Response Regulator) gene family, including PRR9, PRR7, and PRR5, functions in the circadian clock primarily by:
(A) Directly capturing blue light photons.
(B) Synthesizing melatonin in the dark.
(C) Sequentially repressing CCA1 and LHY expression from morning to evening.
(D) Transporting florigen through the phloem.

2007

80. Identify the correct combination of statements about the circadian clock.
I. Entrainment resets the phase of the clock daily.
II. Temperature compensation relies on balanced antagonistic reactions.
III. The clock regulates stomatal opening independently of immediate light perception.
IV. LHY expression strictly requires far-red light to be transcribed.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) I, II and III
(C) II, III and IV
(D) I and III

2007

81. The classical C/N ratio theory of flowering, proposed by Klebs, hypothesized that:
(A) High nitrogen and low carbohydrates promote flowering.
(B) Flowering strictly requires equal molar amounts of carbon and nitrogen.
(C) High carbohydrates and low nitrogen promote reproductive growth.
(D) Nitrogen completely inhibits all aspects of plant growth.

2006

82. Chailakhyan's classical hormonal theory of flowering postulated the existence of two distinct hypothetical hormones called:
(A) Florigen and Vernalin
(B) Gibberellin and Anthesin
(C) Auxin and Cytokinin
(D) Ethylene and Abscisin

2024

83. According to Chailakhyan's expanded bipartite florigen theory, a plant requires which combination to initiate flowering?
(A) High auxin and low cytokinin.
(B) Abscisic acid and ethylene.
(C) Vernalin and high nitrogen.
(D) Gibberellin (for stem elongation) and anthesin (for floral organ formation).

NODIA

2009

84. Bünning's hypothesis, also known as the coincidence model, explains photoperiodism by proposing an internal circadian rhythm with two phases. These phases are:
(A) The photophile (light-loving) and skotophile (dark-loving) phases.
(B) The synthetic and degradation phases.
(C) The juvenile and adult phases.
(D) The vegetative and reproductive phases.

2017

85. In the external coincidence model for long-day plants, flowering is induced when:
(A) External light coincides with the sensitive skotophile phase of the rhythm.
(B) The light period falls strictly within the photophile phase.
(C) External darkness coincides with the photophile phase.
(D) The plant is kept in continuous darkness.

2024

86. Which molecule acts as the key integrator in the external coincidence model of Arabidopsis, where its mRNA peaks in the late afternoon?
(A) CONSTANS (CO)
(B) FLOWERING LOCUS C (FLC)
(C) PHYTOCHROME INTERACTING FACTOR 3 (PIF3)
(D) LEAFY (LFY)

2022

67. Which phenomenon is observed in high-intensity blue light concerning chloroplast positioning, mediated by phototropins?
(A) Chloroplasts gather at the periclinal cell walls to maximize light capture.
(B) Chloroplasts are rapidly degraded into plastoglobuli.
(C) Chloroplasts are entirely expelled from the mesophyll cells.
(D) Chloroplasts move to the anticlinal cell walls to minimize photodamage.

2025

68. The action spectrum of cryptochromes shows peak absorption in which regions?
(A) Far-red and infrared
(B) Blue and UV-A
(C) Green and yellow
(D) UV-C and X-ray

2025

69. Consider the following events during phototropin-mediated stomatal opening and identify their correct sequence.
I. Activation of plasma membrane H^+-ATPase
II. Blue light absorption by LOV domains
III. Influx of potassium (K^+) and water into guard cells
IV. Autophosphorylation of phototropin
(A) II, IV, I, III
(B) I, II, III, IV
(C) II, I, IV, III
(D) IV, II, I, III

2013

70. Identify the correct combination of statements concerning blue-light receptors.
I. Phototropins mediate rapid, directional growth responses.
II. Cryptochromes regulate developmental transitions like flowering.
III. ZTL acts independently of the circadian clock.
Which of the above statement(s) is/are correct?
(A) I and III
(B) I and II
(C) II and III
(D) III

2016

71. A circadian rhythm in plants is defined by an endogenous free-running period of approximately:
(A) 12 hours
(B) 24 hours
(C) 28 days
(D) 365 days

2012

72. Which term describes the synchronization of the internal circadian clock to external environmental cues, such as the daily light-dark cycle?
(A) Emasculation
(B) Vernalization
(C) Stratification
(D) Entrainment

2015

73. A key defining property of circadian rhythms is temperature compensation. This means that:
(A) The period length remains relatively constant across a range of physiological temperatures.
(B) The rhythm ceases completely at high temperatures.
(C) The amplitude of the rhythm doubles with every 10°C increase.
(D) The plant only exhibits rhythms during cold weather.

2010

74. In the Arabidopsis central circadian oscillator, which two single-MYB domain transcription factors peak in the morning and repress evening-phased genes?
(A) TOC1 and GI
(B) CO and FT
(C) FLC and FRI
(D) CCA1 and LHY

2024

75. The evening complex (EC) in the plant circadian clock includes which of the following proteins?
(A) CCA1, LHY, and TOC1
(B) ELF3, ELF4, and LUX
(C) CRY1, CRY2, and PHOT1
(D) PIF3, PIF4, and PIF5

2023

76. What is the functional relationship between CCA1/LHY and TOC1 in the core feedback loop?
(A) CCA1 and LHY repress TOC1 expression, while TOC1 represses CCA1/LHY expression.
(B) CCA1 and LHY activate TOC1 expression, while TOC1 degrades CCA1.
(C) Both sets of genes are exclusively expressed during the night.
(D) They physically bind to each other to form a stable heterohexamer.

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CHAPTER 09
Physiology of Flowering and Reproduction

2018

1. Which of the following fossil taxa is widely considered one of the earliest undisputed angiosperms based on Early Cretaceous records?
(A) Glossopteris
(B) Pentoxylon
(C) Archaefructus
(D) Caytonia

2014

2. According to the anthophyte hypothesis, which gymnosperm group was traditionally, though controversially, considered the closest living relative to angiosperms?
(A) Cycads
(B) Gnetales
(C) Ginkgoales
(D) Coniferales

2003

3. What major evolutionary advantage did the development of the closed carpel provide to early angiosperms?
(A) It eliminated the need for vascular tissue in the floral axis.
(B) It allowed spores to develop without undergoing meiosis.
(C) It replaced the function of leaves in photosynthetic carbon assimilation.
(D) It facilitated pollen tube competition and maternal selection.

2025

4. Which of the following statements INCORRECTLY describes the evolutionary transition of floral organs in early angiosperms?
(A) Carpels originated strictly from modified roots to anchor the ovules.
(B) Stamens evolved from broad, leaf-like microsporophylls.
(C) Petals likely derived from sterilized stamens or modified bracts.
(D) Early flowers were likely variable in organ number and arrangement.

2024

5. In the context of angiosperm evolution, the phenomenon of double fertilization is functionally significant primarily because it:
(A) Prevents the formation of polyploid embryos.
(B) Allows for the simultaneous development of two distinct embryos in one seed.
(C) Ensures that endosperm development is coupled with successful zygote formation.
(D) Halts the vegetative growth of the parent plant permanently.

2010

6. Molecular phylogenetic studies utilizing multiple gene sequences designate which lineage as the basal-most extant angiosperm?
(A) Amborella trichopoda
(B) Magnoliales
(C) Nymphaeales
(D) Ceratophyllum

2010

7. The rapid diversification of angiosperms during the mid-Cretaceous, which Charles Darwin referred to as an "abominable mystery," is most strongly associated with which ecological driver?
(A) The sudden global extinction of all herbivorous dinosaurs.
(B) A drastic drop in atmospheric carbon dioxide levels.
(C) The elimination of all symbiotic mycorrhizal fungi.
(D) Coevolution with specialized insect pollinators.

2013

8. Which floral characteristic is generally considered a derived trait (apomorphic) rather than a basal trait (plesiomorphic) in angiosperm phylogeny?
(A) Numerous, spirally arranged floral organs.
(B) Fused carpels (syncarpy).
(C) Perfect (bisexual) flowers with leaf-like stamens.
(D) Radial symmetry (actinomorphy).

2016

9. Identify the INCORRECT statement regarding the fossil record of early angiosperm pollen.

NODIA

2023

87. Under short-day conditions in Arabidopsis, CONSTANS (CO) protein fails to induce flowering because:
(A) CO mRNA is not transcribed at all.
(B) CO mRNA is exported to the roots.
(C) Short days permanently mutate the CO gene.
(D) The CO protein is translated in the dark and is rapidly degraded by the COP1/SPA1 complex.

2024

88. Consider the following regulatory events in long-day plants and identify their correct chronological sequence.
I. Transcription of FT (FLOWERING LOCUS T)
II. Circadian clock activates CO transcription
III. Light stabilizes CO protein
IV. FT protein moves to shoot apex
(A) II, III, I, IV
(B) I, II, III, IV
(C) III, II, IV, I
(D) II, I, III, IV

2013

89. Which classical experiment provided the strongest physiological evidence for a transmissible floral stimulus (florigen)?
(A) Exposing roots to cold temperatures.
(B) Applying high nitrogen fertilizer to the soil.
(C) Grafting a photoperiodically induced leaf onto a non-induced plant.
(D) Decapitating the apical meristem in the dark.

2017

90. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R). Select the correct option.
Assertion (A): The C/N ratio theory is no longer considered the primary universal mechanism controlling floral induction.
Reason (R): Molecular genetics has shown that specific signaling networks, such as the photoperiodic and vernalization pathways, override bulk nutritional status to trigger flowering.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2008

91. The elusive mobile floral stimulus originally termed "florigen" by Mikhail Chailakhyan has been molecularly identified as the protein product of which gene?
(A) FLOWERING LOCUS T (FT)
(B) FLOWERING LOCUS C (FLC)
(C) CONSTANS (CO)
(D) LEAFY (LFY)

2013

92. Through which vascular tissue does the FT protein travel from its site of synthesis to the shoot apical meristem?
(A) Xylem vessels
(B) Epidermal cell walls
(C) Cortical apoplast
(D) Phloem sieve elements

2017

93. Upon arriving at the shoot apical meristem, the FT protein interacts directly with which basic leucine zipper (bZIP) transcription factor?
(A) LFY
(B) AP1
(C) FD
(D) SOC1

2011

94. The formation of the FT/FD protein complex in the meristem directly activates the transcription of which floral meristem identity gene?
(A) APETALA1 (AP1)
(B) FLC
(C) PHYB
(D) CRY2

2004

95. What structural feature of the FT protein facilitates its symplastic movement through plasmodesmata into the phloem?
(A) It is a massive megadalton complex.
(B) It forms a rigid beta-barrel that punctures cell walls.
(C) It interacts with specific phloem-mobile scaffolding proteins.
(D) It rapidly degrades and moves as free amino acids.

2002

96. Which homologous gene acts as an antagonist to FT, generally repressing flowering and maintaining vegetative growth?
(A) TERMINAL FLOWER 1 (TFL1)
(B) SUPPRESSOR OF OVEREXPRESSION OF CO 1 (SOC1)

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(A) Prevent any possibility of fertilization.
(B) Become completely dependent on wind pollination.
(C) Eliminate its own male reproductive organs.
(D) Ensure basal seed set via autogamy while outcrossing for diversity.

2007

136. Dichogamy promotes outcrossing by:
(A) Temporal separation of pollen release and stigma receptivity.
(B) Spatial separation of anthers and stigmas.
(C) Producing male and female flowers on different plants.
(D) Generating pollen that is lethal to its own stigma.

2024

137. Which molecular marker technique is most effective for distinguishing self-pollinated versus cross-pollinated progeny in a population due to its codominant nature and high polymorphism?
(A) RAPD (Random Amplified Polymorphic DNA)
(B) ISSR (Inter-Simple Sequence Repeat)
(C) AFLP without pedigree data
(D) SSR (Simple Sequence Repeats / Microsatellites)

2010

138. In evaluating outcrossing rates using molecular markers, an excess of homozygotes compared to Hardy-Weinberg expectations typically indicates:
(A) Absolute random mating.
(B) High rates of self-fertilization (autogamy).
(C) Extreme heterozygote advantage.
(D) 100% allogamy.

2011

139. Herkogamy, an adaptation to prevent self-pollination, relies on:
(A) Differential timing of organ maturation.
(B) Chemical incompatibility factors.
(C) Complete absence of petals.
(D) Spatial, morphological separation of anthers and stigmas within a flower.

2007

140. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R). Select the correct option.
Assertion (A): Inbreeding depression is a significant evolutionary constraint on autogamous mating strategies.
Reason (R): Continuous self-fertilization increases the homozygosity of deleterious recessive alleles, reducing overall fitness.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2012

141. The initial adhesion of a pollen grain to a dry stigma is primarily mediated by:
(A) Covalent bonding between cellulose molecules.
(B) The pollen coat (pollenkitt) interacting with the stigma pellicle.
(C) Secretion of vast amounts of sugary exudate by the pollen.
(D) Mechanical hooks on the pollen exine tearing into stigma tissue.

2018

142. What is the defining characteristic of a "wet" stigma?
(A) It lacks specialized epidermal cells (papillae).
(B) It is covered by an intact, continuous cuticle without any secretions.
(C) It is covered by a copious surface secretion of lipids, proteins, and carbohydrates at maturity.
(D) It actively pumps liquid water out to wash away incompatible pollen.

2009

143. During compatible pollen-stigma interactions, pollen hydration on a dry stigma is tightly regulated. Where does the water required for hydration originate?
(A) Exclusively from atmospheric humidity.
(B) From internal reserves within the dehydrated pollen grain itself.
(C) From nectar secreted by the nectaries.
(D) From the stigma papillae, moving across the contact zone.

NODIA

2019

144. Once hydrated, the pollen grain germinates and produces a pollen tube. The growth of this tube is highly polarized and restricted to the:
(A) Apical tip
(B) Tube base
(C) Lateral walls
(D) Entire surface simultaneously

2010

145. Tip growth in pollen tubes is driven by a localized gradient of which essential ion?

(A) High noon when irradiance is maximum.
(B) The exact middle of the dark period.
(C) Midnight exclusively.
(D) The last hours of the dark period and the first hours of the light period.

2014

107. Which morphological trait, aside from stem elongation, is often influenced by diurnal temperature fluctuations?
(A) Primary sequence of DNA
(B) Number of cotyledons in the embryo
(C) Transition from C3 to C4 photosynthesis
(D) Petiole length and leaf orientation (hyponasty)

2016

108. Identify the INCORRECT combination of statements regarding thermoperiodism.
I. Zero DIF means day and night temperatures are equal.
II. Negative DIF increases internode elongation in Lilium.
III. Thermoperiodism can interact synergistically with photoperiodism.
Which of the above statement(s) is/are INCORRECT?
(A) I and II
(B) II
(C) I and III
(D) III

2025

109. If a grower wants to chemically mimic the effect of a negative DIF to reduce stem height, they would most likely apply:
(A) Auxin
(B) Gibberellic acid (GA)
(C) An anti-gibberellin growth retardant (e.g., paclobutrazol)
(D) Salicylic acid

2015

110. Identify the correct combination of statements concerning DIF.
I. Positive DIF increases stem elongation.
II. Negative DIF decreases stem elongation.
III. DIF effects are entirely independent of absolute base temperatures.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I

2013

111. Vernalization is defined as the promotion of flowering by:
(A) Exposure to a brief period of intense heat.
(B) Scratching the seed coat to allow water imbibition.
(C) Exposure to a prolonged period of cold temperatures.
(D) Treating the plant with exogenous cytokinins.

2015

112. The primary site of cold perception for the vernalization response in plants is the:
(A) Mature leaf tissue
(B) Root hairs
(C) Shoot apical meristem and dividing cells
(D) Expanding cotyledons

2002

113. In Arabidopsis thaliana, the requirement for vernalization is primarily enforced by the high expression of which floral repressor gene?
(A) APETALA1 (AP1)
(B) CONSTANS (CO)
(C) FLOWERING LOCUS C (FLC)
(D) LEAFY (LFY)

2005

114. During the process of vernalization, the prolonged cold treatment results in the:
(A) Epigenetic silencing of the FLC locus.
(B) Up-regulation of FLC expression.
(C) Mutation of the FLC gene sequence.
(D) Export of FLC mRNA to the roots.

2008

115. Which epigenetic mechanism is directly responsible for maintaining the repressed state of FLC after the plant returns to warm conditions?
(A) DNA hypermutation
(B) Histone acetylation
(C) Histone H3 lysine 27 trimethylation (H3K27me3) via PRC2
(D) Telomere shortening

2021

116. The gene FRIGIDA (FRI) plays what role in the vernalization pathway of winter-annual Arabidopsis accessions?
(A) It codes for a cold-shock protein that freezes the cell cycle.
(B) It represses FLC, bypassing the need for cold.
(C) It acts as a dominant activator of FLC, creating the vernalization requirement.
(D) It directly activates FT in the leaves.

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2023

155. During GSI in Solanaceae, if self-pollen is recognized, the S-RNase enters the pollen tube and functions by:
(A) Digesting the pollen tube cell wall.
(B) Cleaving the male chromosomes directly.
(C) Inducing programmed cell death in the synergid cells.
(D) Degrading pollen tube ribosomal RNA to arrest translation and growth.

2010

156. In the Brassicaceae family, the Sporophytic Self-Incompatibility (SSI) response occurs very rapidly, typically at which stage?
(A) Deep within the style during tube elongation.
(B) Inside the ovary just before fertilization.
(C) After fertilization, causing seed abortion.
(D) At the stigma surface, preventing pollen hydration or initial germination.

2017

157. The male determinant in the Brassicaceae SSI system is a small, cysteine-rich peptide located in the pollen coat known as:
(A) SCR (or SP11)
(B) SRK
(C) SLG
(D) S-RNase

2017

158. Upon binding of the SCR/SP11 ligand to its specific SRK receptor on the stigma papillae, what molecular event triggers the rejection response?
(A) Autophosphorylation of the SRK intracellular kinase domain.
(B) Rapid degradation of SRK.
(C) Export of S-RNase into the pollen tube.
(D) Synthesis of a new cell wall around the stigma.

2002

159. The S-locus is typically characterized as a single highly polymorphic genetic locus, but it actually consists of:
(A) A single gene coding for both male and female determinants.
(B) Genes spread across three different chromosomes.
(C) Purely repetitive non-coding DNA.
(D) Tightly linked, co-segregating genes encoding distinct male and female determinant proteins.

2018

160. Consider the following events during a generalized self-incompatibility rejection in Brassicaceae and identify their correct chronological sequence.
I. Inhibition of pollen hydration
II. SCR peptide binds to SRK receptor
III. Phosphorylation cascade in stigma papillae
IV. Pollen deposition on stigma
(A) IV, II, III, I
(B) IV, I, II, III
(C) II, IV, III, I
(D) IV, III, II, I

2022

161. True fruit development is defined anatomically as the post-fertilization growth and maturation of the:
(A) Ovule
(B) Receptacle
(C) Ovary
(D) Corolla

2015

162. A fleshy fruit's developmental trajectory typically exhibits an S-shaped (sigmoid) or double-sigmoid growth curve. The initial phase of this curve is characterized primarily by:
(A) Massive cell expansion and vacuolization
(B) Sugar accumulation and ripening
(C) Rapid cell division

2015

163. Following the cell division phase, fruit size increases dramatically during the cell expansion phase. This phase is driven fundamentally by:
(A) Repeated DNA replication without cytokinesis.
(B) Accumulation of massive amounts of structural lignin.
(C) Dehydration of the fruit tissue.
(D) Turgor pressure and the relaxation of cell wall extensibility.

NODIA

2024

164. Which class of phytohormones is primarily supplied by the developing seeds to stimulate the initial growth and cell division of the surrounding ovary tissue?
(A) Auxins and Gibberellins
(B) Ethylene
(C) Abscisic acid
(D) Brassinosteroids

2003

165. Parthenocarpy refers to the:
(A) Development of a seed without fertilization

(A) FT and SOC1
(B) FLC and FRI
(C) PHYA and PHYB
(D) CCA1 and LHY

2016

127. SOC1 is a MADS-box transcription factor that is repressed by:
(A) CONSTANS (CO)
(B) Gibberellic acid (GA)
(C) FLOWERING LOCUS T (FT)
(D) FLOWERING LOCUS C (FLC)

2023

128. How does the age pathway ensure that plants eventually flower even in the absence of favorable environmental cues?
(A) Through the gradual increase in miR156 levels, which degrades SPL transcription factors.
(B) Through the gradual decrease in miR156 levels, leading to increased SPL transcription factor activity that activates SOC1 and LFY.
(C) By accumulating toxic metabolic byproducts that kill vegetative meristems.
(D) By completely shutting down the autonomous pathway.

2003

129. If an Arabidopsis plant contains null mutations in both the photoperiodic and autonomous pathways, its flowering phenotype would likely be:
(A) Extremely early flowering.
(B) Flowering at the exact same time as wild-type.
(C) Severely delayed or completely non-flowering.
(D) Instantaneous flowering at the cotyledon stage.

2004

130. Match the items in List I with those in List II.
List I: (Flowering pathway)
P. Photoperiodic
Q. Vernalization
R. Autonomous
S. Gibberellin
List II: (Key regulatory mechanism or component)
1. FLC repression via RNA binding proteins like FCA
2. External coincidence model and CONSTANS
3. Upregulation of LFY and SOC1 under short days
4. PRC2-mediated epigenetic silencing of FLC
(A) P-2, Q-4, R-1, S-3
(B) P-4, Q-2, R-3, S-1
(C) P-1, Q-3, R-4, S-2
(D) P-2, Q-1, R-4, S-3

2018

131. Cleistogamy is a plant mating strategy characterized by:
(A) Flowers that open wide to attract a diverse range of pollinators.
(B) The production of only male flowers on a plant.
(C) Seed development without any fertilization.
(D) Flowers that never open, enforcing obligate self-pollination.

2015

132. Which of the following defines chasmogamous flowers?
(A) They remain tightly closed throughout their lifespan.
(B) They open normally to facilitate cross-pollination (allogamy).
(C) They lack stamens entirely.
(D) They mature underground.

2006

133. Allogamy, or cross-fertilization, provides which primary evolutionary advantage to a plant population?
(A) Guaranteed reproductive success even if pollinators are absent.
(B) Conservation of exactly the same maternal genotype.
(C) Increased genetic diversity and potential for adaptation.
(D) Drastic reduction in floral energy expenditure.

2012

134. Autogamy is favored in ecological scenarios where:
(A) Pollinator populations are sparse and unpredictable.
(B) Inbreeding depression is extremely high.
(C) The environment is highly variable and rapidly changing.
(D) The plant produces large, highly fragrant, nectar-rich flowers.

2016

135. Many plant species produce both cleistogamous and chasmogamous flowers on the same individual. This mixed mating system allows the plant to:

NODIA

2003

175. The physiological function of LEA proteins is generally considered to be:
(A) Catalyzing the breakdown of starch during germination.
(B) Digesting the seed coat to allow water entry.
(C) Absorbing far-red light to maintain dormancy.
(D) Protecting cell structures from desiccation and preventing protein aggregation.

2002

176. Which phytohormone peaks during the maturation phase of seed development and is absolutely required for inducing primary dormancy and desiccation tolerance?
(A) Gibberellic acid
(B) Indole-3-acetic acid
(C) Abscisic acid (ABA)
(D) Zeatin

2005

177. Seed storage proteins (e.g., globulins and prolamins) are synthesized on the rough endoplasmic reticulum and stored securely inside:
(A) Chloroplasts
(B) Nuclei
(C) Protein bodies (specialized vacuoles)
(D) Mitochondria

2003

178. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R). Select the correct option.
Assertion (A): Orthodox seeds can survive extreme drying to very low moisture contents.
Reason (R): The accumulation of non-reducing sugars and LEA proteins during maturation creates a glassy state that stabilizes cellular membranes.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2005

179. Recalcitrant seeds differ from orthodox seeds primarily because they:
(A) Require a period of after-ripening before germination.
(B) Do not acquire desiccation tolerance and die if dried below critical moisture levels.
(C) Germinate only in complete darkness.
(D) Have extremely thick, impermeable seed coats.

2011

180. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R). Select the correct option.
Assertion (A): Vivipary, the precocious germination of seeds on the parent plant, is commonly observed in ABA-deficient mutants.
Reason (R): ABA is essential for promoting rapid cell division in the apical meristem during mid-embryogenesis.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2021

181. Seed and fruit abortion commonly occurs as a plant's mechanism to regulate crop load. This phenomenon is often termed:
(A) Parthenocarpy
(B) Vivipary
(C) Physiological fruit drop
(D) Apomixis

2001

182. A major environmental stress factor that frequently induces high rates of early fruit and seed abortion in many crop plants is:
(A) Adequate soil nitrogen
(B) High temperature stress during anthesis and early post-fertilization
(C) Optimal diurnal temperatures
(D) Mild wind

2008

183. From a physiological standpoint, fruit abortion occurs because developing fruits are intense sinks that compete for:
(A) Soil structural aggregates
(B) Atmospheric oxygen
(C) Limited photoassimilates (carbohydrates) from source leaves
(D) Far-red light

2009

184. The phenomenon of "dominance" among developing fruits on the same raceme often leads to the abortion of later-set fruits. This is largely governed by:
(A) Vascular continuity and sink strength established by the earlier fruits.

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(A) Potassium (K^+)
(B) Sodium (Na^+)
(C) Chloride (Cl^-)
(D) Calcium ($Ca^{\{2+\}}$)

2021

146. Which structural component is synthesized rapidly at the extreme apex of the growing pollen tube to allow expansion while maintaining integrity?
(A) Lignin
(B) Callose
(C) Pectins
(D) Suberin

2002

147. As the pollen tube elongates through the transmitting tract of the style, it is isolated from older sections of the tube by the periodic deposition of:
(A) Cellulose cross-walls
(B) Casparian strips
(C) Lignin rings
(D) Callose plugs

2006

148. Identify the correct combination of statements concerning pollen tube guidance.
I. The transmitting tissue of the style provides mechanical and nutritional support.
II. LURE peptides secreted by the synergid cells act as species-specific attractants.
III. The pollen tube directly enters the egg cell without rupturing.
IV. GABA gradients in the pistil contribute to initial tube growth directionality.
(A) I, II and IV
(B) II, III and IV
(C) I, III and IV
(D) I, II, III and IV

2017

149. The process by which the pollen tube is attracted towards the female gametophyte is an example of:
(A) Phototropism
(B) Thigmotropism
(C) Chemotropism
(D) Gravitropism

2003

150. Identify the correct combination of statements regarding pollen-pistil interactions.
I. Dry stigmas typically regulate hydration more stringently than wet stigmas.
II. Dry stigmas possess a proteinaceous pellicle.
III. The stigma acts as the first checkpoint for species-specific recognition.
IV. Stigmatic exudates on wet stigmas often contain lipids to reduce water evaporation.
(A) I, II, III and IV
(B) I and II
(C) II and III
(D) III and IV

2018

151. Self-incompatibility (SI) is a genetic mechanism utilized by angiosperms to:
(A) Promote self-fertilization in isolated environments.
(B) Halt embryo development post-fertilization.
(C) Force the production of cleistogamous flowers.
(D) Prevent inbreeding and promote outcrossing by rejecting self-pollen.

NODIA

2024

152. In Sporophytic Self-Incompatibility (SSI), the compatibility phenotype of the pollen grain is determined by the:
(A) Haploid genotype of the individual pollen grain.
(B) Environmental temperature during microsporogenesis.
(C) Genotype of the maternal stigma.
(D) Diploid genotype of the paternal plant that produced the pollen.

2006

153. Gametophytic Self-Incompatibility (GSI) implies that a pollen grain will be rejected if its:
(A) Diploid paternal S-alleles match the stigma's alleles.
(B) Single haploid S-allele differs entirely from the pistil's S-alleles.
(C) Both haploid S-alleles match.
(D) Single haploid S-allele matches either of the two S-alleles in the diploid pistil.

2004

154. In the widely studied Solanaceae family, the GSI system relies on the activity of which female determinant secreted into the stylar extracellular matrix?
(A) S-locus Receptor Kinase (SRK)
(B) S-locus Cysteine-Rich protein (SCR)
(C) S-RNase (Ribonuclease)
(D) F-box protein (SLF)

2021

117. What happens to the vernalized state (FLC repression) during meiosis and gametogenesis?
(A) It becomes permanently fixed in the genome for all future generations.
(B) It is erased, resetting the high FLC expression level in the next generation.
(C) It spreads to neighboring genes, silencing the whole chromosome.
(D) It causes the seed to abort if not exposed to cold again immediately.

2003

118. Identify the correct combination of statements regarding vernalization.
I. It prevents premature flowering during warm autumn days.
II. VERNALIZATION INSENSITIVE 3 (VIN3) is induced by cold and helps assemble the PRC2 complex at FLC.
III. Vernalization effects can typically be perceived by completely dormant dry seeds.
IV. The suppression of FLC is an example of mitotic cellular memory.
(A) I, II and IV
(B) II, III and IV
(C) I, III and IV
(D) I, II and III

2016

119. Some plants, like winter wheat, can perceive vernalization during:
(A) Only the adult vegetative phase.
(B) Only after floral evocation has begun.
(C) Only the completely dry seed stage.
(D) Seed germination (imbibed seed stage) as well as the vegetative phase.

2011

120. Identify the INCORRECT combination of statements regarding vernalization.
I. Devernalization can occur if cold treatment is immediately followed by high temperatures.
II. FLC is a floral activator.
III. Cool temperatures (0-10°C) are typically required for weeks to months.
IV. FLC encodes a MADS-box transcription factor.
Which of the above statement(s) is/are INCORRECT?
(A) I and II
(B) II
(C) III and IV
(D) I and III

2002

121. In Arabidopsis, the control of flowering time is governed by several integrated genetic pathways. Which of the following is NOT typically recognized as a primary flowering pathway?
(A) Photoperiodic pathway
(B) Vernalization pathway
(C) Nitrogen-fixation pathway
(D) Gibberellin pathway

2017

122. The autonomous flowering pathway promotes flowering independently of environmental signals primarily by:
(A) Activating CONSTANS expression.
(B) Repressing FLC expression via RNA processing and chromatin modification.
(C) Synthesizing high levels of abscisic acid.
(D) Altering the circadian clock period.

2010

123. The genes FCA, FY, and FPA belong to which flowering pathway?
(A) Photoperiodic
(B) Vernalization
(C) Autonomous
(D) Gibberellin

2023

124. Under strictly non-inductive short days, wild-type Arabidopsis depends almost entirely on which pathway to eventually trigger flowering?
(A) Vernalization pathway
(B) Photoperiodic pathway
(C) Ethylene pathway
(D) Gibberellin (GA) pathway

2011

125. Consider the following signaling nodes in the Arabidopsis flowering network and identify their correct hierarchical sequence from upstream integrators to downstream identity genes.
I. FLOWERING LOCUS T (FT)
II. APETALA1 (AP1)
III. CONSTANS (CO)
IV. SUPPRESSOR OF OVEREXPRESSION OF CO 1 (SOC1)
(A) III, I, IV, II
(B) I, III, II, IV
(C) III, IV, I, II
(D) IV, I, III, II

2003

126. Which two genes are widely considered the central "floral integrators" that converge signals from all major flowering pathways?

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(apomixis).
(B) Shedding of immature fruits.
(C) Ripening of fruits strictly in the dark.
(D) Development of a fruit without successful fertilization or seed formation.

2019

166. Climacteric fruit ripening is characterized by a distinct burst in cellular respiration and the autocatalytic synthesis of:
(A) Auxin
(B) Abscisic acid
(C) Ethylene
(D) Cytokinin

2007

167. Which of the following is an example of a non-climacteric fruit?
(A) Tomato
(B) Banana
(C) Strawberry
(D) Apple

2013

168. Match the items in List I with those in List II.
List I: (Fruit ripening changes)
P. Softening
Q. Sweetening
R. Color change (green to red/yellow)
S. Aroma development
List II: (Biochemical cause)
1. Synthesis of volatile organic compounds
2. Degradation of chlorophyll and synthesis of carotenoids/anthocyanins
3. Breakdown of starch into simple sugars
4. Depolymerization of pectins by polygalacturonase
(A) P-4, Q-3, R-2, S-1
(B) P-3, Q-4, R-1, S-2
(C) P-4, Q-2, R-3, S-1
(D) P-1, Q-4, R-3, S-2

2015

169. During seed development, the suspensor primarily functions to:
(A) Store massive amounts of starch for germination.
(B) Push the embryo proper into the nutrient-rich endosperm and transfer nutrients.
(C) Develop into the primary root system.
(D) Form the hard, impermeable seed coat.

2022

170. Match the items in List I with those in List II.
List I: (Stage of seed development)
P. Histodifferentiation
Q. Maturation phase
R. Desiccation
S. Germination
List II: (Primary physiological event)
1. Rapid cell division and formation of basic body plan
2. Severe loss of water to 5-15% moisture content
3. Accumulation of storage reserves (proteins, lipids, starch)
4. Radicle emergence
(A) P-1, Q-3, R-2, S-4
(B) P-3, Q-1, R-4, S-2
(C) P-1, Q-2, R-3, S-4
(D) P-2, Q-3, R-1, S-4

2010

171. In typical dicot embryogenesis, the first division of the zygote is usually asymmetric, establishing the apical-basal axis. The smaller apical cell gives rise to the:
(A) Embryo proper
(B) Suspensor
(C) Basal cell
(D) Endosperm

2005

172. The central cell of the embryo sac, upon fertilization by a sperm cell, develops into a triploid tissue known as the:
(A) Perisperm
(B) Testa
(C) Nucellus
(D) Endosperm

NODIA

2021

173. What is the primary role of the endosperm in seed biology?
(A) To provide structural armor against predators.
(B) To serve as a nutritive tissue supplying the developing or germinating embryo.
(C) To synthesize the pigments for the fruit exocarp.
(D) To anchor the seed to the soil surface.

2015

174. During the later stages of seed maturation, seeds synthesize large quantities of LEA proteins. What does LEA stand for?
(A) Late Embryogenesis Abundant
(B) Light Emitting Amino acids
(C) Low Energy Activation
(D) Leaf Epidermis Associated

(C) GIGANTEA (GI)
(D) AGAMOUS (AG)

2014

97. The structural similarity between FT and TFL1 proteins is striking, yet they have opposite functions. This difference is primarily attributed to:
(A) A difference of over 100 amino acids.
(B) TFL1 being synthesized exclusively in roots.
(C) FT possessing a massive kinase domain lacking in TFL1.
(D) Substitution of a single critical amino acid in the binding pocket.

2015

98. Systemic signaling in flowering refers to the phenomenon where:
(A) The floral signal is generated in the meristem and stays there.
(B) Perception of the environmental cue in one organ (leaf) generates a mobile signal that triggers a response in a distant organ (meristem).
(C) The entire plant cell completely reorganizes its DNA.
(D) Roots generate light to illuminate the dark soil.

2005

99. In an experiment, if the FT gene is genetically modified to be expressed exclusively under a meristem-specific promoter rather than a leaf-specific promoter, what is the likely outcome?
(A) The plant will fail to flower entirely.
(B) The plant will flower without needing the photoperiodic signal in the leaf.
(C) The phloem will become completely blocked.
(D) Leaves will transform into flower petals.

2016

100. Match the items in List I with those in List II.
List I: (Molecular components)
P. PHYB perception
Q. CONSTANS (CO) protein accumulation
R. FT protein movement
S. FT/FD complex formation
List II: (Location of action)
1. Shoot apical meristem
2. Leaf phloem companion cells
3. Leaf mesophyll/epidermis
4. Phloem sieve tube elements
(A) P-3, Q-2, R-4, S-1
(B) P-2, Q-3, R-1, S-4
(C) P-1, Q-4, R-2, S-3
(D) P-3, Q-1, R-4, S-2

2016

101. Thermoperiodism refers to a plant's physiological and developmental responses to:
(A) Extreme heat stress exceeding 40°C.
(B) Freezing temperatures during the winter season.
(C) Diurnal alternating fluctuations between day and night temperatures.
(D) Continuous constant temperatures grown in vitro.

2003

102. The concept of DIF in greenhouse horticulture is calculated as:
(A) Day temperature minus Night temperature.
(B) Day temperature multiplied by Night temperature.
(C) Night temperature minus Day temperature.
(D) Average daily temperature divided by photoperiod.

2003

103. A positive DIF (day temperature higher than night temperature) typically promotes which morphological response in many commercial floriculture crops?
(A) Extreme dwarfism
(B) Leaf abscission
(C) Tuberization
(D) Increased internode elongation and stem height

2021

104. Which hormonal pathway is most directly modulated by DIF to regulate stem elongation?
(A) Etheline biosynthesis
(B) Gibberellin biosynthesis and sensitivity
(C) Abscisic acid catabolism
(D) Cytokinin transport

2011

105. A negative DIF (cooler days, warmer nights) is frequently used commercially to achieve which desired plant characteristic?
(A) Rapid seed germination
(B) Taller stems for cut flowers
(C) Compact, shorter pot plants without chemical growth retardants
(D) Delayed fruit ripening

2023

106. Thermoperiodic responses are generally most sensitive during which specific time window of the diurnal cycle?

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(B) The physical weight of the earlier fruits pulling off the later ones.
(C) Toxic gases released by older fruits.
(D) Older fruits physically blocking light from newer fruits.

2005

185. Incomplete fertilization due to poor pollen viability or failed pollen tube growth often leads directly to:
(A) Massive fruit gigantism
(B) Seed abortion and subsequent fruit drop
(C) Delayed fruit ripening
(D) Parthenocarpic fruit development in all species

2022

186. Which hormone is commonly synthesized in the pedicel abscission zone in response to stress or failed seed development, triggering fruit drop?
(A) Auxin
(B) Ethylene
(C) Cytokinin
(D) Gibberellin

2016

187. Stenospermocarpy is a specific condition where:
(A) Fertilization never occurs, yet the fruit grows.
(B) Multiple embryos develop from a single fertilized egg.
(C) The fruit grows entirely inside the stem.
(D) Fertilization occurs, but the embryos abort early, resulting in seedless fruits.

2010

188. Identify the INCORRECT combination of statements regarding seed abortion.
I. Abortion is always a pathological defect and never an adaptive trait.
II. Resource limitation is a primary driver of selective seed abortion.
III. Seeds with severe genetic anomalies often abort due to endosperm failure.
IV. Endosperm development is crucial for embryo survival.
(A) I
(B) II and III
(C) I and IV
(D) II

2025

189. Genetic incompatibilities between maternal tissue and the endosperm can lead to post-zygotic reproductive isolation, resulting in:
(A) Immediate flowering
(B) Seed abortion
(C) Polyembryony
(D) Enhanced seed vigor

2006

190. Identify the correct combination of statements concerning fruit drop.
I. High sink competition leads to assimilate starvation in weaker fruits.
II. A drop in endogenous auxin exported from the fruit promotes abscission layer formation.
III. Ethylene application suppresses fruit abortion completely.
IV. The "June drop" in apples is an example of physiological fruit abscission.
(A) I, II and IV
(B) I, II and III
(C) II, III and IV
(D) I, III and IV

2019

191. To chemically thin heavy crop loads and induce controlled fruit abortion early in the season, orchardists often apply:
(A) Pure water sprays
(B) Cytokinin pastes
(C) Synthetic auxins or ethylene-releasing compounds.
(D) Heavy nitrogen fertilizers

2005

192. Conversely, if a grower wants to prevent pre-harvest fruit drop in mature fruits (e.g., apples), they might apply exogenous:
(A) Ethylene gas
(B) Abscisic acid
(C) Synthetic auxins (to counteract ethylene sensitivity in the abscission zone)
(D) Salicylic acid

2008

193. Exogenous application of gibberellic acid (GA) is commercially used on seedless grapes (e.g., Thompson Seedless) specifically to:
(A) Induce rapid seed abortion.
(B) Promote berry enlargement and rachis elongation in stenospermocarpic fruits.
(C) Prevent the synthesis of sugars.
(D) Shrink the fruit size to fit packaging.

NODIA

2022

194. In tissue culture, rescuing aborting interspecific hybrid embryos before they die relies on cultivating the excised embryo on media rich in:
(A) Sucrose, amino acids, and precise hormonal balances.

ANSWERS

1. (C) Archaefructus
Archaefructus is identified as an ancient fossil taxon from the Early Cretaceous period, often regarded as one of the earliest undisputed angiosperms. It lacks sepals and petals, bearing reproductive organs on an elongated stem. This discovery significantly influenced modern understanding of early flowering plant evolution and their aquatic or semi-aquatic ecological origins.

2. (B) Gnetales
The anthophyte hypothesis traditionally proposed that Gnetales were the closest living relatives to angiosperms due to shared morphological features like flower-like reproductive structures and vessel elements. Although molecular data now largely refutes this connection, it remains a significant historical theory in plant phylogenetics regarding the transition from gymnosperms to flowering plants.

3. (D) It facilitated pollen tube competition and maternal selection.
The development of the closed carpel represents a critical evolutionary milestone for angiosperms. This structure completely encloses the ovules, providing protection and requiring pollen grains to grow long tubes through the style. This anatomical barrier facilitates intense competition among pollen tubes, allowing maternal tissues to select the most vigorous male gametophytes for fertilization.

4. (A) Carpels originated strictly from modified roots to anchor the ovules.
Floral organs in early angiosperms are generally understood to be modified leaves rather than root-derived structures. The carpel likely evolved from a folded megasporophyll that enclosed the ovules for protection. Stamens frequently originated from broad, leaf-like microsporophylls, while petals often derived from sterilized stamens or bracts through subsequent evolutionary modifications during floral diversification.

5. (C) Ensures that endosperm development is coupled with successful zygote formation.
Double fertilization is a unique process in angiosperms where two sperm cells fuse with the egg and the central cell respectively. This mechanism ensures that the nutrient-rich endosperm tissue only develops if fertilization of the egg is successful. Such synchronization prevents the plant from wasting significant metabolic resources on seeds that do not contain a viable embryo.

6. (A) Amborella trichopoda
Molecular phylogenetic analyses consistently place Amborella trichopoda as the single sister group to all other living flowering plants. This unique shrub, endemic to New Caledonia, lacks vessel elements in its xylem, a feature typical of more basal lineages. Its position provides essential insights into the ancestral genomic and morphological state of the earliest diverging angiosperm ancestors.

7. (D) Coevolution with specialized insect pollinators.
The rapid diversification of angiosperms during the mid-Cretaceous is frequently attributed to their complex coevolutionary relationships with specialized insect pollinators. This biotic interaction allowed for efficient pollen transfer and promoted reproductive isolation among diverging populations. Specialized floral structures emerged to attract specific insects, accelerating the rate of speciation and establishing flowering plants as dominant terrestrial organisms.

8. (B) Fused carpels (syncarpy).
In angiosperm evolution, the fusion of carpels, known as syncarpy, is considered a derived or apomorphic characteristic compared to the ancestral state of separate carpels. This trait enhances reproductive efficiency by providing a unified site for pollen tube entry and selection. Basal lineages typically exhibit numerous, spirally arranged, and free floral organs rather than fused or whorled structures.

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2024

205. Consider the following events leading to pollen abortion in a typical CMS system and identify their correct chronological sequence.
I. Accumulation of cytotoxic chimeric protein
II. Transcription of the chimeric mitochondrial ORF
III. Premature programmed cell death of the tapetum
IV. Starvation and degradation of developing microspores
(A) II, I, III, IV
(B) I, II, III, IV
(C) II, III, I, IV
(D) III, II, I, IV

2025

206. The T-urf13 protein in CMS-T maize exhibits dual toxicity. Besides causing male sterility, it made the maize plants disastrously susceptible to which fungal pathotoxin?
(A) Victorin from Cochliobolus victoriae
(B) Fumonisin from Fusarium
(C) AAL-toxin from Alternaria
(D) T-toxin from Bipolaris maydis (Southern corn leaf blight)

2011

207. Why is CMS an extremely valuable tool in commercial agriculture?
(A) It dramatically increases the nutritional value of the grain.
(B) It allows for cost-effective hybrid seed production without manual emasculation.
(C) It allows crops to grow without any fertilizer.
(D) It makes the plants completely immune to all insect pests.

2025

208. In many CMS systems, the defect leading to sterility is physically manifested as the malfunctioning of which critical anther tissue layer?
(A) Epidermis
(B) Endothecium
(C) Tapetum
(D) Middle layer

2013

209. Which energetic disruption is frequently cited as the physiological consequence of the CMS chimeric proteins inserted into the inner mitochondrial membrane?
(A) Extreme overproduction of ATP causing cells to burst.
(B) Creation of non-specific pores causing a loss of membrane potential and ATP depletion.
(C) Complete blockage of glycolysis in the cytosol.
(D) Immediate destruction of chloroplast photosystems.

2014

210. CMS relies on maternal inheritance. If a CMS female parent (A-line) is pollinated by a normal male fertile maintainer line (B-line), the resulting progeny will be:
(A) 100% Male Fertile
(B) 100% Male Sterile
(C) 50% Fertile, 50% Sterile
(D) Completely inviable

2008

211. Fertility restoration in CMS systems is achieved by dominant nuclear genes. What is the standard abbreviation for these restorer genes?
(A) CMS genes
(B) S-alleles
(C) Cry genes
(D) Rf genes (Restorer of fertility)

2005

212. Most classical Rf genes encode a specific class of RNA-binding proteins that target mitochondrial transcripts. These proteins are known as:
(A) MADS-box proteins
(B) Pentatricopeptide Repeat (PPR) proteins
(C) Leucine-Rich Repeat (LRR) proteins
(D) Cytochrome P450s

2023

213. How do Rf PPR proteins generally neutralize the sterile phenotype at the molecular level?
(A) By directly degrading the entire mitochondrial genome.
(B) By binding to the anomalous CMS transcript and promoting its cleavage, degradation, or altering its translation.
(C) By replacing the mitochondria with chloroplasts.
(D) By secreting hormones that bypass the need for pollen.

2006

214. In a three-line hybrid seed production system (A, B, and R lines), the A-line is sterile (S rfrf), and the B-line is the fertile maintainer (N rfrf). What must the genotype of the R-line (Restorer) be to produce 100% fertile F1 hybrid seeds?
(A) S rfrf
(B) N rfrf
(C) N or S RfRf

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(B) Herbicides
(C) Toxic metals
(D) Absolute darkness without carbon

2015

195. Which physiological intervention can physically reduce sink competition and thereby decrease abortion rates of the remaining fruits?
(A) Removing 90% of the plant's mature leaves.
(B) Pruning or mechanically thinning a portion of the flowers/young fruits.
(C) Shading the entire plant completely.
(D) Severing the root system.

2015

196. The application of anti-ethylene compounds like 1-MCP (1-methylcyclopropene) or AVG (aminoethoxyvinylglycine) can influence fruit drop by:
(A) Destroying the vascular cambium.
(B) Inhibiting ethylene action or synthesis to delay abscission zone activation.
(C) Accelerating the degradation of all cellular proteins.
(D) Blocking photosynthesis in the fruit skin.

2018

197. Which macronutrient deficiency is strongly correlated with increased flower and fruit abortion due to its critical role in pollen tube growth and cell wall stability?
(A) Nitrogen
(B) Phosphorus
(C) Potassium
(D) Boron and Calcium

2018

198. Exogenous cytokinin application to developing fruits can mitigate abortion under stress primarily by:
(A) Hastening fruit senescence.
(B) Increasing local sink strength, enhancing the drawing power of assimilates to the fruit.
(C) Inducing complete stomatal closure permanently.
(D) Breaking down starch into toxic alcohols.

2005

199. Consider the following physiological events during normal fruit abscission and identify their correct sequence.
I. Synthesis of cellulase and polygalacturonase in the abscission zone
II. Reduction of auxin flux from the fruit
III. Separation of cells and fruit drop
IV. Increased ethylene sensitivity in the abscission zone
(A) II, IV, I, III
(B) I, II, III, IV
(C) IV, I, II, III
(D) II, I, IV, III

2016

200. The concept of "sink strength" is mathematically described as:
(A) Sink size divided by sink activity.
(B) Sink size multiplied by sink activity.
(C) Photosynthetic rate minus respiration rate.
(D) Transpiration pull multiplied by root pressure.

2018

201. Cytoplasmic Male Sterility (CMS) is a maternally inherited trait characterized by the plant's inability to:
(A) Produce viable female ovules.
(B) Form petals and sepals.
(C) Produce functional pollen.
(D) Absorb water through its roots.

2012

202. The genetic determinants responsible for Cytoplasmic Male Sterility are primarily located in the genome of the:
(A) Nucleus
(B) Chloroplast
(C) Mitochondrion
(D) Endoplasmic reticulum

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2018

203. The molecular basis of CMS usually involves the expression of anomalous, chimeric open reading frames (ORFs). These are typically generated by:
(A) Point mutations in nuclear DNA.
(B) Viral infections integrating into the chloroplast.
(C) Spontaneous polyploidy events.
(D) Extensive genomic rearrangements within mitochondrial DNA.

2004

204. Which well-known chimeric mitochondrial gene is responsible for the Texas (T) cytoplasm male sterility in maize?
(A) urf13 (T-urf13)
(B) orf138
(C) orf79
(D) pcf

(A) The physical linkage of genes on the same chromosome.
(B) Non-allelic gene interactions where the effect of one gene locus masks or modifies the effect of another.
(C) The complete silencing of maternal genes.
(D) Random mutation rates in hybrids.

2018

225. At the physiological and metabolic level, heterosis is frequently associated with:
(A) Decreased photosynthetic efficiency.
(B) Enhanced energy use efficiency and improved carbon assimilation.
(C) Slower rates of cell division.
(D) Complete dependence on anaerobic fermentation.

2022

226. Recent transcriptomic and epigenetic studies suggest that heterosis may partly arise from altered gene expression patterns in hybrids compared to parents. This includes:
(A) Transgressive segregation of lethal traits.
(B) Non-additive gene expression and altered DNA methylation levels at specific loci.
(C) Absolute silencing of all transcription factors.
(D) Spontaneous chromosome fragmentation.

2023

227. In the context of heterosis, what happens when superior F1 hybrids are allowed to self-pollinate to produce an F2 generation?
(A) The vigor increases further.
(B) The F2 generation maintains the exact same vigor as the F1.
(C) Inbreeding depression occurs, leading to phenotypic segregation and vigor loss.
(D) The F2 generation becomes entirely polyploid.

2013

228. Identify the INCORRECT combination of statements regarding heterosis.
I. Commercial corn (maize) production heavily relies on heterosis.
II. Heterosis is strictly limited to cross-pollinated species and cannot occur in self-pollinated crops like rice.
III. Standard heterosis is measured relative to the best commercial variety, whereas heterobeltiosis is measured against the better parent.
IV. High general combining ability (GCA) in parental lines is crucial for developing vigorous hybrids.
(A) I and III
(B) II
(C) III and IV
(D) I and II

2003

229. Which biochemical parameter is sometimes used as an early marker to predict the extent of heterosis in developing hybrids?
(A) Lignin deposition in the root cap.
(B) Mitochondrial complementation and enhanced respiratory efficiency in vitro.
(C) The rate of chlorophyll degradation in darkness.
(D) Complete absence of amylase activity.

2011

230. Identify the correct combination of statements concerning the genetic basis of heterosis.
I. The dominance hypothesis relies on the complementation of deleterious recessive alleles.
II. Single-gene overdominance is universally accepted as the sole cause of yield heterosis.
III. Epistatic interactions involve synergistic effects between different gene loci.
IV. Heterosis often involves both additive and non-additive genetic variances.
(A) I, III and IV
(B) I, II and IV
(C) II, III and IV
(D) I, II and III

****

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to flowering. Fluctuations in intracellular calcium concentrations help relay external environmental signals and internal hormonal cues to the gene expression machinery. This signaling pathway is essential for coordinating the complex series of biochemical and cellular events that transform the vegetative apex into a reproductive floral meristem.

37. (D) In situ hybridization
In situ hybridization is the most appropriate technique for visualizing the spatiotemporal expression of floral meristem identity genes at the histological level. By using labeled nucleic acid probes, researchers can detect exactly where and when specific mRNAs are transcribed within the tissue sections of the meristem. This provides a detailed map of the molecular changes that drive the morphological transition.

38. (B) Targeted demethylation of specific floral promoter regions.
The activation of floral genes during the transition to flowering is typically associated with the targeted demethylation of specific promoter regions. DNA methylation is an epigenetic mechanism often used to silence genes during the juvenile or vegetative phases. Removing these methyl groups allows the transcriptional machinery to access the DNA, facilitating the expression of genes required for reproductive development.

39. (C) Carbon / Nitrogen
The Klebs hypothesis, an early physiological theory, proposed that the transition to flowering is governed by the relative concentrations of internal nutrients. Specifically, a high ratio of carbon to nitrogen was thought to favor reproductive growth over vegetative growth. While modern molecular genetics has revealed more complex signaling pathways, the bulk nutritional status of the plant still influences the timing of flowering.

40. (A) Both A and R are true and R is the correct explanation of A.
During floral evocation, the shoot apical meristem physically expands and typically takes on a more domed appearance. This morphological change is a direct result of the synchronization of cell divisions and the expansion of the central zone. These cellular adjustments are required to accommodate the rapid initiation and growth of the various floral organ primordia that replace vegetative leaf primordia.

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41. (C) The relative lengths of day and night.
Photoperiodism is the physiological response of plants to the relative lengths of the light and dark periods in a twenty-four-hour cycle. This mechanism allows plants to sense seasonal changes and time critical events, such as flowering, according to the time of year. Many species use the duration of the continuous night period as the primary cue for developmental transitions.

42. (B) The continuous dark period exceeds a critical minimum duration.
A short-day plant will only initiate flowering when the continuous dark period exceeds a specific critical minimum duration. Although called short-day plants, they are technically long-night plants because the length of the uninterrupted darkness is the determining factor. If this dark period is interrupted by even a brief flash of light, flowering is typically inhibited, regardless of the overall day length.

43. (D) To ensure flowering occurs during the increasing day lengths of spring or early summer.
Long-day plants are ecologically adapted to flower during the late spring or early summer when day lengths are increasing. This strategy ensures that the plant completes its reproductive cycle before the onset of winter frost in temperate regions. By responding to longer photoperiods, these plants can maximize their growth during the most favorable months and ensure seeds mature while temperatures are warm.

44. (A) Regardless of the photoperiod, depending primarily on developmental age or biomass.
Day-neutral plants are characterized by their ability to flower regardless of the prevailing photoperiod. In these species, the transition to reproductive growth is primarily regulated by internal developmental factors, such as plant age, size, or the number of leaves produced. This independence from day length allows them to flower across a wide range of latitudes and seasons if conditions are suitable.

45. (C) It inhibits flowering by breaking the critical dark period.
In a strict short-day plant, a brief flash of red light during the middle of the dark period inhibits

9. (C) The earliest angiosperm pollen lacked complex exine ornamentation.
Early angiosperm pollen was characterized by diverse and sometimes complex exine ornamentations, contrary to the assumption that they were structurally simple. These microscopic features are crucial for identifying early fossil lineages in the stratigraphic record. While early pollen was often monosulcate, the evolution of tricolpate pollen later marked the emergence of the large eudicot clade during radiation.

10. (A) P-2, Q-3, R-1, S-4
Amborella trichopoda is a basal angiosperm naturally lacking vessels, while the extinct Bennettitales possessed flower-like reproductive organs. Syncarpy involves the fusion of carpels, which enhances pollen tube competition during the fertilization process. Triploid endosperm is the characteristic product of double fertilization in most flowering plants, serving as a vital nutrient source for the developing embryo.

11. (A) A transition in leaf morphology, phyllotaxy, and rooting ability.
The transition from the juvenile to the adult vegetative phase in plants involves significant morphological and physiological changes. These shifts often include alterations in leaf shape, the arrangement of leaves on the stem, and the ability to form adventitious roots. This phase change ensures the plant achieves sufficient size and structural integrity before entering the final reproductive stage.

12. (B) Vegetative maturity is the acquisition of adult traits; reproductive competence is readiness to respond to floral signals.
Vegetative maturity refers to the acquisition of adult physical characteristics and growth patterns, whereas reproductive competence is the physiological readiness of the plant to respond to floral induction signals. A plant may reach vegetative maturity yet still require specific environmental triggers, like photoperiod or temperature changes, to actually initiate the formation of flowers and reproductive organs.

13. (B) Palmate, lobed leaves and plagiotropic (creeping) growth.
English ivy serves as a classic model for studying phase changes due to its distinct juvenile and adult forms. The juvenile phase is characterized by palmate, lobed leaves and a creeping, plagiotropic growth habit that facilitates ground coverage. In contrast, the adult phase exhibits entire, ovate leaves and an upright, orthotropic habit, eventually leading to terminal flowering and seed production.

14. (A) The scion retains its reproductive competence and can flower.
Grafting experiments demonstrate that the physiological state of reproductive competence is largely maintained within the scion. When a mature, flowering scion is grafted onto a juvenile rootstock, it typically continues to produce flowers rather than reverting to a juvenile state. This indicates that the signals for phase maintenance or transition are often localized or autonomously regulated within the shoot.

15. (C) Allows for biomass accumulation and canopy dominance before energy allocation to reproduction.
The prolonged juvenile phase in forest trees is an ecological strategy that prioritizes vegetative growth and structural stability. By delaying reproductive competence, trees can allocate energy toward biomass accumulation and reaching the forest canopy. This dominance ensures they have access to adequate light and resources before investing significant metabolic energy into the production of seeds and floral structures.

16. (D) miR156 and miR172
The transition from juvenile to adult phases is primarily regulated by the sequential and antagonistic actions of two microRNAs. Levels of miR156 are high during the juvenile stage and gradually decrease over time. Conversely, miR172 levels increase as the plant matures, promoting the expression of adult traits and facilitating the eventual transition toward reproductive competence and flowering.

17. (C) SPL (Squamosa Promoter Binding Protein-Like)
The decrease in miR156 concentration during plant development allows for the up-regulation of the SPL transcription factor family. miR156 acts by post-transcriptionally repressing SPL mRNAs during the juvenile phase. Once this repression is lifted, SPL proteins promote the expression of adult vegetative traits and eventually activate downstream genes that trigger the formation of the first floral primordia.

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18. (A) II, IV, I, III
The developmental life cycle of a typical angiosperm begins with embryogenesis inside the seed. Following germination, the plant enters the juvenile vegetative phase, characterized by specific leaf forms and an inability to flower. As growth continues, it reaches the vegetative mature phase, eventually acquiring reproductive competence to enter the final reproductive phase where flowers and fruits are produced.

19. (D) GA applications can induce phase reversion from adult back to juvenile.
Gibberellic acid plays a complex and often species-specific role in plant phase transitions. In many woody angiosperms, exogenous applications of gibberellic acid can actually induce phase reversion, causing an adult plant to return to juvenile morphological characteristics. This response highlights the hormonal regulation of phase identity and its impact on traits like leaf shape and adventitious rooting potential.

20. (A) Both A and R are true and R is the correct explanation of A.
Juvenile plant tissues generally exhibit a significantly higher potential for adventitious root formation compared to adult tissues. This physiological capability is attributed to higher endogenous auxin levels and a lower concentration of specific rooting inhibitors within the juvenile cells. These biochemical conditions create a favorable environment for the initiation of root primordia from stem cuttings or other organs.

21. (C) Reproducing only once before naturally senescing and dying.
Semelparity is an evolutionary life history strategy where an organism reproduces only once during its entire lifespan. After this single reproductive event, the plant typically undergoes rapid senescence and dies. This strategy often involves the production of a massive number of offspring, ensuring that at least some seeds survive despite the inevitable death of the parent plant post-flowering.

22. (A) Iteroparous
Iteroparity describes a life strategy where an individual plant undergoes multiple reproductive cycles throughout its lifetime. These plants, often referred to as polycarpic, do not die after the first flowering event. Instead, they maintain vegetative meristems that allow for continued growth and subsequent flowering in following seasons, a common trait among many perennial herbs and woody forest trees.

23. (D) Monocarpic perennial
Agave americana is classified as a monocarpic perennial because it lives for many years in a vegetative state before flowering once and then dying. Although it is a perennial based on its long lifespan, its single reproductive event aligns with the semelparous strategy. Such plants accumulate massive resource reserves over decades to support the production of their large, energy-intensive inflorescences.

24. (B) Hormone-regulated nutrient mobilization from vegetative tissues to developing seeds.
Whole-plant senescence in monocarpic species is primarily triggered by the massive mobilization of nutrients from vegetative organs to the developing seeds. This hormone-regulated process ensures that reproductive success is maximized at the expense of parental survival. As carbohydrates and minerals are drained from leaves and stems to support the offspring, the vegetative tissues lose functionality and eventually die.

25. (C) I and III
Iteroparous plants allocate significant resources toward survival and maintenance to ensure multiple reproductive cycles. In many monocarpic species, removing developing flowers or fruits can effectively delay whole-plant senescence by preventing the nutrient drain associated with seed set. However, not all monocarpic plants are annuals; some, like certain bamboos and agaves, can live for many years before flowering.

26. (D) Semelparity
Semelparity is theoretically favored in environments where adult mortality is high or unpredictable, but conditions for seed germination and juvenile survival are relatively favorable. In such cases, investing all available resources into a single, massive reproductive effort maximizes the probability of passing on genes before the adult dies. This strategy contrasts with iteroparity, which is more successful in stable environments.

27. (A) By maintaining a population of active vegetative meristems that do not convert to floral meristems.
Perennial polycarpic plants avoid whole-plant senescence by ensuring that only a portion of

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their meristems convert into floral structures during each reproductive season. A population of active vegetative meristems is always maintained to continue the plant's growth after the seeds have matured. This spatial separation of reproductive and vegetative functions allows the individual to survive and produce flowers over successive years.

28. (B) Cytokinin
Cytokinins are well-known for their anti-senescence properties in plants. When applied exogenously to the leaves of monocarpic species, they can significantly delay the onset of whole-plant senescence by maintaining chlorophyll levels and promoting nutrient retention in vegetative tissues. This hormone acts antagonistically to signals like ethylene and abscisic acid, which typically accelerate the degradation of cellular components post-flowering.

29. (B) Iteroparous species are limited to annual and biennial growth habits.
Iteroparity is not limited to annual or biennial habits; in fact, it is the defining strategy of most perennial plants, including forest trees and many herbaceous species. These organisms balance their resource allocation between current reproduction and future survival. This strategy is generally advantageous in stable environments where juvenile mortality is high, as it allows for multiple reproductive opportunities.

30. (A) Iteroparous – Polycarpic
The terms iteroparous and polycarpic are essentially synonymous in botanical and ecological contexts. Both describe organisms that reproduce more than once during their lifespan. Similarly, semelparous and monocarpic are used interchangeably to describe plants that die after a single reproductive event. Understanding these terminologies is fundamental to studying the diverse life history strategies evolved by different plant lineages across ecosystems.

31. (C) Mobilization and transport of sucrose from mature source leaves.
The sudden accumulation of carbohydrates in the shoot apical meristem before floral evocation is primarily due to the mobilization of sucrose from mature source leaves. As the plant transitions to flowering, the meristem becomes a powerful sink, drawing in sugars through the phloem. This surge in energy is essential to support the increased metabolic demands required for floral initiation.

32. (D) Pentose phosphate pathway
During the transition to flowering, the pentose phosphate pathway is significantly up-regulated in the apical meristem. This metabolic shift provides necessary precursors for nucleotide biosynthesis and generates reducing power in the form of NADPH. These components are vital for supporting the rapid cell proliferation and biosynthetic activities that occur as the vegetative meristem reorganizes into a complex reproductive structure.

33. (D) The irreversible commitment of the apical meristem to form floral primordia.
Floral evocation specifically refers to the stage where the shoot apical meristem becomes irreversibly committed to the formation of floral primordia. This process occurs in response to various internal and environmental signals that reach the apex. Once evocation is complete, the meristem undergoes a series of morphological and histological changes, even if the inductive signals are subsequently removed.

34. (A) A surge in mitotic activity in the central zone, altering the tunica-corpus zonation.
One of the earliest histological markers of the transition to flowering is a surge in mitotic activity within the central zone of the shoot apical meristem. This change alters the traditional tunica-corpus zonation and often results in the meristem becoming larger and more domed. These structural modifications are necessary to provide enough cells for the subsequent initiation of numerous floral primordia.

35. (C) I and IV
During floral evocation, RNA synthesis actually increases significantly in the meristem to support the production of new proteins required for floral development. Furthermore, the mitotic index typically rises rather than decreases, reflecting the rapid cell division taking place. While protein synthesis inhibitors can indeed block the transition and ATP levels rise, the initial statements regarding RNA and mitosis are incorrect.

36. (A) Calcium ions ($Ca^{\{2+\}}$)
Calcium ions act as critical secondary messengers in the shoot apical meristem during the transition

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(D) Completely null for Rf

2006

215. Consider the following steps of the three-line hybrid seed production process and identify their correct chronological sequence.
I. F1 hybrid seeds are sold to farmers and grow into fertile plants.
II. A-line is crossed with R-line to produce F1 hybrid seed.
III. A-line is maintained by crossing with B-line.
(A) III, II, I
(B) II, I, III
(C) I, II, III
(D) III, I, II

2004

216. In the CMS-WA (Wild Abortive) system used extensively in hybrid rice, what is the fate of the microspores?
(A) They mature normally but cannot germinate on the stigma.
(B) They convert into female egg cells.
(C) They fuse to form giant multinucleated syncytia.
(D) They abort early at the uninucleate stage due to tapetal abnormalities.

2002

217. While most Rf genes encode PPR proteins, the Rf2 gene in the maize CMS-T system encodes a completely different enzyme. What is it?
(A) A mitochondrial aldehyde dehydrogenase.
(B) A highly active ribonuclease.
(C) A DNA polymerase.
(D) A cellulase.

2016

218. An interesting deviation from RNA-level restoration is seen in CMS-Boro II (CMS-BT) rice. How does the restorer gene Rf1a function here?
(A) It prevents the transcription of the orf79 gene.
(B) It acts as a physical plug in the mitochondrial pore.
(C) It mutates the nuclear DNA to resist the toxin.
(D) It promotes cleavage of the atp6-orf79 mRNA to prevent toxic ORF79 translation.

2011

219. The evolutionary dynamic between novel CMS mitochondrial mutations and the emergence of nuclear Rf genes is best described as:
(A) Sympatric speciation
(B) Intracellular genomic coevolution (or "arms race")
(C) Horizontal gene transfer
(D) Genetic drift

2003

220. For crops where the economic product is the vegetative part (e.g., cabbage, onion), which of the following is true regarding hybrid production?
(A) An Rf restorer line is absolutely required.
(B) An Rf restorer line is NOT required, as fertility in the F1 is unnecessary for harvest.
(C) The crop must be grown in total darkness.
(D) The F1 hybrid must be artificially emasculated.

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2009

221. Heterosis, or hybrid vigor, refers to the phenomenon where:
(A) The F1 hybrid exhibits an inferior phenotype compared to its parents.
(B) The F1 hybrid demonstrates superior phenotypic traits (e.g., yield, growth rate) compared to the average or the best of its homozygous parents.
(C) The F1 hybrid becomes sterile.
(D) The F1 hybrid spontaneously mutates its chloroplast DNA.

2019

222. The "Dominance Hypothesis" of heterosis proposes that hybrid vigor results from:
(A) The interaction of completely new genes found only in the hybrid.
(B) The masking of deleterious recessive alleles from one parent by dominant favorable alleles from the other parent.
(C) The over-expression of both recessive alleles.
(D) The rapid elimination of dominant alleles during mitosis.

2014

223. The "Overdominance Hypothesis" suggests that heterosis occurs because:
(A) The heterozygous state (Aa) at a single locus is inherently physiologically superior to both homozygous states (AA or aa).
(B) All alleles in the genome are dominant.
(C) Dominant alleles from different loci complement each other.
(D) The hybrid has double the number of chromosomes.

2007

224. Epistasis is also considered a major contributor to heterosis. Epistasis refers to:

flowering. This phenomenon occurs because the light pulse breaks the critical continuous dark period required for floral induction. The phytochrome system perceives this red light, converting the inactive Pr form to the active Pfr form, which signals the plant that the night has been interrupted.

46. (D) Photoperiods between a specific minimum and maximum length to flower.
Intermediate-day plants are a specialized category that require a photoperiod within a narrow range, between a specific minimum and maximum length, to flower. If the day length is either too short or too long, these plants will remain in a vegetative state. This precise requirement ensures that flowering occurs only during specific seasonal windows when environmental conditions and pollinator availability are optimal.

47. (A) Pharbitis nil (Japanese morning glory)
Pharbitis nil, commonly known as Japanese morning glory, is a classic model species used in the study of photoperiodism. It is an obligate short-day plant, meaning it has a strict requirement for long nights to initiate flowering. Research on this species has provided fundamental insights into the perception of light signals in the leaves and the subsequent transmission of the floral stimulus.

48. (B) Remain vegetative.
If a long-day plant has a critical day length of 14 hours, it must be exposed to a photoperiod longer than this threshold to flower. Being exposed to only 13 hours of light means the day is too short to trigger the reproductive transition. Consequently, the plant will remain in its vegetative phase, continuing to produce leaves rather than initiating the development of flower buds.

49. (C) Mature leaf blade
The mature leaf blade is the primary site for the perception of photoperiodic signals in higher plants. Photoreceptors like phytochromes and cryptochromes in the leaf detect the light-dark cycle and initiate a signaling cascade. This process eventually leads to the production of a mobile floral stimulus, which travels from the leaf to the shoot apical meristem to trigger flowering.

50. (A) P-3, Q-4, R-1, S-2
Short-day plants flower when the dark period exceeds a critical length, while long-day plants require day lengths exceeding a critical threshold. Day-neutral plants flower regardless of the day length, based on internal developmental age. Long-short-day plants have a more complex requirement, needing a sequence of long days followed by short days to successfully transition to the reproductive stage.

51. (D) Pfr, which absorbs far-red light.
Phytochromes exist in two interconvertible forms: Pr and Pfr. The Pfr form is generally considered the biologically active state that initiates photomorphogenic responses in plants. Pfr is formed upon the absorption of red light by the Pr form. Once active, Pfr absorbs far-red light, which converts it back to the inactive Pr form, thus acting as a reversible light-sensitive switch.

52. (B) 660 nm
The Pr form of phytochrome has a peak absorption wavelength in the red region of the spectrum, specifically around 660 nm. Upon absorbing red light at this wavelength, the molecule undergoes a conformational change to become the active Pfr form. This light-mediated transformation is the basis for many plant developmental responses, including seed germination, seedling de-etiolation, and the timing of flowering.

53. (A) Phytochromobilin
The light-absorbing component of the phytochrome molecule is an open-chain tetrapyrrole chromophore known as phytochromobilin. This chromophore is covalently attached to the apoprotein and is responsible for the characteristic red and far-red absorption properties. The isomerization of the chromophore upon light absorption triggers conformational changes in the protein that lead to biological activity and signal transduction throughout the plant.

54. (A) Low Fluence Response (LFR)
Low Fluence Responses are a category of phytochrome-mediated responses that are fully reversible by far-red light. These responses obey the law of reciprocity, meaning the effect depends on the total number of photons regardless of the duration of exposure. Examples of these responses include the induction of seed

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germination in certain species and the regulation of leaf movements in response to light.

55. (C) Depends on the continuous presence of light and irradiance level.
High Irradiance Responses differ from Low Fluence Responses because they require the continuous presence of light and are dependent on the irradiance level rather than the total light dose. Unlike LFR, High Irradiance Responses are not fully reversible by far-red light and typically operate under prolonged exposure to high-intensity light. These responses are crucial for seedling establishment and anthocyanin synthesis.

56. (C) Nucleus
Upon conversion from the inactive Pr form to the active Pfr form, phytochrome typically translocates from the cytosol into the nucleus. Inside the nucleus, the Pfr form interacts with various transcription factors, such as Phytochrome Interacting Factors, to regulate the expression of light-responsive genes. This movement is a critical step in the signal transduction pathway that translates light perception into development.

57. (A) I and II
Phytochrome A is light-labile, meaning it is rapidly degraded by proteasomes after being converted to its Pfr form. In contrast, Phytochrome B is light-stable and is the primary receptor mediating responses like shade avoidance in mature plants. While both types are involved in light sensing, they respond differently to light quality and duration, ensuring proper plant adaptation to the environment.

58. (A) A low Red to Far-Red (R:FR) ratio.
The shade avoidance syndrome is triggered in sun-adapted plants by a low ratio of red to far-red light. Leaves of competing plants absorb red light for photosynthesis but reflect or transmit far-red light, reducing the R:FR ratio in the understory. Phytochromes perceive this change, leading to increased stem elongation and reduced branching as the plant attempts to reach sunlight.

59. (D) Histidine kinase-related domain (HKRD)
The C-terminal region of the phytochrome apoprotein contains a histidine kinase-related domain. This domain is essential for the molecule's autophosphorylation and signaling functions. Although plant phytochromes function primarily as serine/threonine kinases in eukaryotes, the presence of this domain reflects their evolutionary origins from ancestral bacterial phytochromes, which are part of two-component signaling systems involving histidine phosphorylation.

60. (A) Both A and R are true and R is the correct explanation of A.
Very Low Fluence Responses are characterized by extreme sensitivity to light and a lack of far-red reversibility. These responses require such a minute conversion of Pr to Pfr that even exposure to far-red light establishes enough Pfr to trigger the response. This explains why some seeds can germinate after exposure to very dim, transient light signals in the soil.

61. (B) Hypocotyl elongation inhibition and photoperiodic flowering
Cryptochromes are blue/UV-A light receptors that play essential roles in inhibiting hypocotyl elongation during seedling de-etiolation and regulating the timing of photoperiodic flowering. They sense blue light and coordinate developmental responses by interacting with other proteins like COP1 and various transcription factors. This ensures that the plant develops correctly in response to the light environment during early life stages.

62. (A) FAD and MTHF (pterin)
Plant cryptochromes utilize two non-covalently bound chromophores to absorb light: flavin adenine dinucleotide and 5,10-methenyltetrahydrofolate. FAD is the primary chromophore that undergoes photoreduction upon blue light absorption, while MTHF serves as a light-harvesting antenna pigment. The energy captured by these chromophores triggers conformational changes in the cryptochrome protein, initiating downstream signaling events in the plant that regulate growth.

63. (C) Phototropism, chloroplast movement, and stomatal opening
Phototropins are a distinct class of blue light receptors that primarily regulate directional and movement-related responses. These include phototropism, the movement of chloroplasts within cells to optimize light capture, and the opening of stomata to facilitate gas exchange.

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Unlike cryptochromes, which often regulate long-term developmental changes, phototropins mediate rapid physiological responses to the immediate light environment throughout the plant's life.

64. (A) LOV (Light, Oxygen, Voltage) domains
Phototropins contain specialized light-sensing regions known as LOV domains, which stand for Light, Oxygen, and Voltage. These domains bind a flavin mononucleotide chromophore that forms a covalent bond with a conserved cysteine residue upon blue light absorption. This photochemical reaction induces a structural change in the protein, activating its kinase domain and initiating the signaling cascade for light-induced movements.

65. (C) They are the primary receptors for red-light induced seed germination.
The ZEITLUPE family of photoreceptors primarily perceives blue light through a LOV domain rather than red light. These proteins are characterized by an F-box domain, which targets specific circadian clock and flowering proteins for ubiquitination and subsequent degradation. They do not serve as the primary receptors for red-light induced germination, which is a process mediated exclusively by the phytochrome system.

66. (A) By binding to and inhibiting COP1, preventing the degradation of HY5.
Activated cryptochromes promote photomorphogenesis by binding to and inhibiting the E3 ubiquitin ligase COP1. In the dark, COP1 normally targets the transcription factor HY5 for degradation, preventing light-regulated growth. When blue light activates cryptochrome, it disrupts COP1 activity, allowing HY5 to accumulate in the nucleus. HY5 then promotes the expression of genes necessary for de-etiolation and chlorophyll synthesis.

67. (D) Chloroplasts move to the anticlinal cell walls to minimize photodamage.
Under high-intensity blue light, chloroplasts exhibit an avoidance response mediated by phototropins. They move away from the upper and lower surfaces of the cell and gather along the anticlinal cell walls. This movement minimizes photodamage to the photosynthetic apparatus. In low light, they gather at the periclinal walls to maximize light absorption for photosynthesis, optimizing energy efficiency and protection.

68. (B) Blue and UV-A
Cryptochromes are characterized by an action spectrum with peak absorption in the blue and UV-A regions of the electromagnetic spectrum. This absorption profile is determined by the properties of their flavin and pterin chromophores. These receptors allow plants to sense and respond to the presence of blue light, which is particularly important for regulating seedling development and the circadian clock.

69. (A) II, IV, I, III
Blue light-mediated stomatal opening begins with the absorption of light by the LOV domains of phototropin. This triggers the autophosphorylation of the phototropin protein, activating its signaling pathway. Subsequently, the plasma membrane H^+-ATPase is activated, pumping protons out of the guard cell and creating an electrochemical gradient. This gradient drives the influx of potassium ions and water, opening the stoma.

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70. (B) I and II
Phototropins are primarily responsible for mediating rapid, directional growth and movement responses, such as phototropism and stomatal opening. Cryptochromes, on the other hand, play a key role in regulating major developmental transitions, including the timing of flowering and seedling establishment. While ZEITLUPE is also a photoreceptor, it functions as an integral part of the circadian clock system.

71. (B) 24 hours
A circadian rhythm is an internal biological process that oscillates with an endogenous free-running period of approximately twenty-four hours. These rhythms persist even in the absence of external environmental cues, such as continuous light or darkness. They allow plants to anticipate daily changes in their environment and coordinate physiological activities, like photosynthesis and leaf movements, with the Earth's day-night cycle.

72. (D) Entrainment
Entrainment is the process by which an internal biological clock is synchronized to external environmental cues, known as zeitgebers. The most common zeitgebers are the daily transitions between light and dark and fluctuations in temperature. Entrainment ensures that the plant's internal rhythms are perfectly

aligned with the twenty-four-hour cycle of the environment, maximizing physiological efficiency and survival across seasons.

73. (A) The period length remains relatively constant across a range of physiological temperatures.
Temperature compensation is a defining property of circadian rhythms that ensures the period length remains relatively constant despite fluctuations in environmental temperature. Typically, metabolic reactions speed up as temperature increases, but the circadian clock maintains its twenty-four-hour cycle through complex antagonistic mechanisms. This stability allows the plant to keep accurate biological time regardless of seasonal or daily weather changes.

74. (D) CCA1 and LHY
In the Arabidopsis circadian clock, CCA1 and LHY are two single-MYB domain transcription factors that reach their peak expression in the morning. These proteins function together to repress the expression of evening-phased genes, such as TOC1. As their levels decline throughout the day, the repression is lifted, allowing evening genes to be transcribed and completing a core part of the feedback loop.

75. (B) ELF3, ELF4, and LUX
The evening complex is a vital component of the plant circadian clock that functions during the night. It is composed of three proteins: EARLY FLOWERING 3, EARLY FLOWERING 4, and LUX ARRHYTHMO. This complex acts as a transcriptional repressor, targeting genes that are expressed during the day and early evening, thereby helping to maintain the proper timing and phase.

76. (A) CCA1 and LHY repress TOC1 expression, while TOC1 represses CCA1/LHY expression.
The core of the Arabidopsis circadian oscillator involves a reciprocal negative feedback loop. CCA1 and LHY are morning-expressed proteins that bind to the promoter of the TOC1 gene and repress its transcription. Conversely, TOC1 is an evening-expressed protein that represses the expression of CCA1 and LHY. This mutual inhibition, along with other regulatory layers, generates the robust oscillation of the clock.

77. (D) Light/dark transitions
Light/dark transitions are the most potent environmental signals, or zeitgebers, for entraining the circadian clock in plants. The daily onset of light at dawn and the transition to darkness at dusk provide precise timing cues that reset the phase of the internal clock. This ensures that the plant's physiological processes are correctly synchronized with the solar day, optimizing growth success.

78. (B) Continue to oscillate for several days with a period of roughly 24 hours.
When a plant is moved from a regular light/dark cycle into continuous darkness, its circadian rhythms, such as leaf movements, will continue to oscillate for several days. This persistence occurs because the rhythms are driven by an endogenous biological clock rather than by immediate environmental changes. The period of these free-running oscillations is approximately twenty-four hours, though it may gradually dampen.

79. (C) Sequentially repressing CCA1 and LHY expression from morning to evening.
The Pseudo-Response Regulator gene family plays a crucial role in the circadian clock by providing sequential repression of the morning genes, CCA1 and LHY. Different proteins, such as PRR9, PRR7, and PRR5, are expressed at various times from morning until evening. This sequential activity forms multiple feedback loops that refine the clock's timing and enhance its robustness under environmental conditions.

80. (B) I, II and III
Entrainment daily resets the phase of the circadian clock to match the environment, while temperature compensation ensures the period remains stable despite temperature changes. The clock also regulates processes like stomatal opening independently of immediate light perception. However, the expression of the morning gene LHY is not strictly dependent on far-red light, as it is primarily controlled by internal oscillators.

81. (C) High carbohydrates and low nitrogen promote reproductive growth.
Klebs proposed that the balance of internal nutrients, specifically the carbon-to-nitrogen ratio, determines whether a plant remains vegetative or becomes reproductive. According to this theory, high carbohydrate levels combined with low nitrogen availability promote flowering and reproductive growth. While bulk nutrient

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status does influence development, modern research shows that specific signaling pathways generally override these metabolic ratios to control flowering.

82. (B) Gibberellin and Anthesin
Mikhail Chailakhyan's hormonal theory of flowering proposed the existence of a complex called florigen, which he later hypothesized consisted of two distinct components: gibberellin and anthesin. He suggested that gibberellins were responsible for stem elongation and the formation of the floral axis, while anthesin was the specific stimulus for the development of floral organs. Together, these substances coordinate flowering.

83. (D) Gibberellin (for stem elongation) and anthesin (for floral organ formation).
According to Chailakhyan's bipartite florigen theory, a plant must possess both gibberellin and the hypothetical hormone anthesin to initiate the flowering process. Gibberellins are known to promote stem growth, while anthesin was proposed as the actual signal for floral organogenesis. This model attempted to explain how various internal and environmental factors converge to trigger the complex transition from vegetative to reproductive growth.

84. (A) The photophile (light-loving) and skotophile (dark-loving) phases.
Bünning's coincidence model for photoperiodism proposes that plants possess an internal circadian rhythm consisting of two distinct phases: the photophile and the skotophile phase. The photophile phase typically occurs during the day, while the skotophile phase occurs during the night. The plant's photoperiodic response is determined by whether light or darkness coincides with the corresponding phase of this internal rhythm.

85. (A) External light coincides with the sensitive skotophile phase of the rhythm.
In the external coincidence model for long-day plants, flowering is induced when the external light period coincides with the sensitive skotophile phase of the internal circadian rhythm. This occurs when the days are long enough for light to persist into the time when the plant is internally primed for its dark-loving phase. This coincidence triggers the molecular signals that lead to flowering.

86. (A) CONSTANS (CO)
The CONSTANS protein acts as the central integrator in the external coincidence model of Arabidopsis. The transcription of the CO gene is regulated by the circadian clock, with mRNA levels peaking in the late afternoon. In long-day conditions, this peak in mRNA coincides with exposure to light, which stabilizes the CO protein and allows it to activate floral induction.

87. (D) The CO protein is translated in the dark and is rapidly degraded by the COP1/SPA1 complex.
Under short-day conditions in Arabidopsis, the CONSTANS protein fails to induce flowering because its peak mRNA expression occurs after sunset. Although the mRNA is translated into protein during the night, the CO protein is unstable in the dark and is rapidly degraded by the COP1/SPA1 ubiquitin ligase complex. Without sufficient CO protein accumulation during the light period, flowering is not triggered.

88. (A) II, III, I, IV
The regulation of flowering in long-day plants begins with the circadian clock activating the transcription of the CONSTANS gene. When the days are long, the resulting CO protein is stabilized by light. This stable CO protein then activates the transcription of the FLOWERING LOCUS T gene in the leaves. Finally, the FT protein moves from the leaf to the shoot apex.

89. (C) Grafting a photoperiodically induced leaf onto a non-induced plant.
The strongest physiological evidence for a transmissible floral stimulus came from grafting experiments. When a leaf from a plant that had been exposed to its inductive photoperiod was grafted onto a plant kept under non-inductive conditions, the recipient plant was triggered to flower. This demonstrated that a mobile signal is generated in the leaves and travels to the distant meristem.

90. (A) Both A and R are true and R is the correct explanation of A.
The C/N ratio theory is no longer considered the primary universal mechanism for floral induction. Modern molecular genetics has demonstrated that specific signaling networks, such as the photoperiodic and vernalization pathways, integrate various environmental and internal cues. These precise molecular mechanisms typically override the plant's bulk nutritional

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127. (D) FLOWERING LOCUS C (FLC)
SOC1 is a MADS-box transcription factor that plays a key role as a floral integrator. Its expression is directly repressed by the potent floral inhibitor FLOWERING LOCUS C. This repression is one of the primary mechanisms by which FLC prevents flowering during the vegetative phase. Only when FLC levels are reduced, through processes like vernalization, can SOC1 be expressed to promote development.

128. (B) Through the gradual decrease in miR156 levels, leading to increased SPL transcription factor activity that activates SOC1 and LFY.
The age pathway ensures that plants eventually flower by utilizing a gradual decrease in the levels of miR156 as the plant grows older. This reduction in miR156 leads to an increase in the activity of SPL transcription factors. These SPL proteins then activate floral integrators like SOC1 and meristem identity genes like LEAFY, ensuring the plant transitions even without inductive environmental signals.

129. (C) Severely delayed or completely non-flowering.
If an Arabidopsis plant lacks functional photoperiodic and autonomous pathways, its ability to flower will be severely compromised. These two pathways are the primary drivers of the transition to reproductive growth under most conditions. Without them, the plant would have high levels of the floral repressor FLC and no way to stabilize the CONSTANS protein, resulting in a non-flowering phenotype.

130. (A) P-2, Q-4, R-1, S-3
The photoperiodic pathway involves the external coincidence model and CONSTANS, while the vernalization pathway relies on PRC2-mediated epigenetic silencing of FLC. The autonomous pathway involves FLC repression through RNA binding proteins like FCA. Finally, the gibberellin pathway contributes to flowering by up-regulating genes such as LFY and SOC1, particularly under short-day conditions where other inductive signals may be absent.

131. (D) Flowers that never open, enforcing obligate self-pollination.
Cleistogamy is a specialized mating strategy where plants produce flowers that never open. This morphology enforces obligate self-pollination, as the pollen is released and reaches the stigma within the protected environment of the closed bud. This strategy ensures reproductive success even in the absence of pollinators or during unfavorable environmental conditions, although it limits the genetic diversity of the resulting offspring.

132. (B) They open normally to facilitate cross-pollination (allogamy).
Chasmogamous flowers are the standard type of flowers that open normally at maturity. Their open structure facilitates the transfer of pollen by various agents, such as insects, wind, or birds, thereby promoting cross-pollination. This mating strategy increases the potential for genetic recombination and diversity within a population, which is essential for long-term adaptation and evolution in changing environmental conditions across habitats.

133. (C) Increased genetic diversity and potential for adaptation.
Allogamy, or cross-fertilization, provides the primary evolutionary advantage of increasing genetic diversity within a plant population. By combining genetic material from two different individuals, the resulting offspring possess new allele combinations. This diversity enhances the population's ability to adapt to environmental changes, resist diseases, and avoid the negative effects of inbreeding depression, which can occur during repeated self-fertilization.

134. (A) Pollinator populations are sparse and unpredictable.
Autogamy, or self-fertilization, is often favored in ecological scenarios where pollinator populations are sparse or unpredictable. In such environments, relying on cross-pollination might result in reproductive failure. Self-fertilization provides a reproductive assurance mechanism, ensuring that the plant can produce seeds and maintain its population even when external agents for pollen transfer are unavailable, a common trait in colonizing species.

135. (D) Ensure basal seed set via autogamy while outcrossing for diversity.
A mixed mating system, where a plant produces both cleistogamous and chasmogamous flowers, offers a balanced reproductive strategy. The closed cleistogamous flowers ensure a guaranteed basal level of seed set through reliable self-pollination, requiring minimal energy investment. Meanwhile, the open chasmogamous flowers

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100. (A) P-3, Q-2, R-4, S-1
PHYB perception primarily occurs in the leaf tissues, while the CONSTANS protein accumulates in the phloem companion cells of the leaf. The FT protein travels through the phloem sieve tube elements to reach its destination. Finally, the formation of the FT/FD protein complex takes place in the shoot apical meristem, where it activates the genes required to initiate flowers.

101. (C) Diurnal alternating fluctuations between day and night temperatures.
Thermoperiodism refers to the physiological and developmental responses of plants to diurnal alternating fluctuations between day and night temperatures. Many plants grow better and exhibit more robust development when exposed to these natural temperature cycles rather than a constant temperature. This phenomenon is separate from responses to extreme heat or cold and is critical in both natural and agricultural environments.

102. (A) Day temperature minus Night temperature.
In greenhouse horticulture, the concept of DIF is calculated as the mathematical difference between the day temperature and the night temperature. This value can be positive, negative, or zero, depending on whether the day is warmer, cooler, or the same temperature as the night. Managing the DIF is a standard technique used by growers to control plant height and morphological characteristics.

103. (D) Increased internode elongation and stem height
A positive DIF typically promotes increased internode elongation and overall stem height in many floriculture crops. This response is frequently used in commercial production when taller plants are desired. The physiological basis for this effect involves changes in the levels and sensitivity of hormones, such as gibberellins, which drive the expansion of cells in the stems according to the temperature cycle.

104. (B) Gibberellin biosynthesis and sensitivity
The DIF response in plants is most directly associated with the modulation of the gibberellin hormonal pathway. Fluctuations in diurnal temperature affect both the biosynthesis of gibberellins and the plant's sensitivity to them. A positive DIF increases GA activity, leading to greater stem elongation, while a negative DIF reduces GA effects, resulting in more compact growth and sturdier stems.

105. (C) Compact, shorter pot plants without chemical growth retardants
A negative DIF is frequently used by commercial growers to produce compact, shorter pot plants. This technique provides an effective alternative to chemical growth retardants for controlling height. By reducing the temperature during the day or the first few hours of light, internode elongation is inhibited, resulting in plants that are sturdier and more aesthetically pleasing for the consumer market.

106. (D) The last hours of the dark period and the first hours of the light period.
Thermoperiodic responses are generally most sensitive during a specific window of the diurnal cycle, typically the last few hours of the dark period and the first few hours of the light period. Temperature changes during this transition time have the most significant impact on stem elongation. Growers often target this period with temperature adjustments to maximize the effectiveness of DIF management.

107. (D) Petiole length and leaf orientation (hyponasty)
In addition to stem elongation, diurnal temperature fluctuations also influence traits such as petiole length and leaf orientation, a phenomenon known as hyponasty. These changes affect the overall architecture of the plant and its ability to capture light. The management of DIF can thus be used to fine-tune various aspects of plant morphology, ensuring that crops develop an optimal structure.

108. (B) II
The statement that negative DIF increases internode elongation in Lilium is incorrect; in fact, negative DIF is specifically used to decrease elongation and produce shorter plants. Zero DIF means day and night temperatures are equal, and thermoperiodic responses can indeed interact with photoperiodism to influence plant development. Understanding these relationships is essential for effective crop management and achieving desired morphological traits.

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status to trigger the developmental switch from vegetative growth to flowering appropriately.

91. (A) FLOWERING LOCUS T (FT)
The elusive mobile floral stimulus, originally called florigen, has been molecularly identified as the protein product of the FLOWERING LOCUS T gene. FT is synthesized in the leaves in response to inductive photoperiodic signals and then travels to the shoot apical meristem. Once at the apex, it triggers the genetic program that transforms the vegetative meristem into a floral meristem.

92. (D) Phloem sieve elements
The FT protein is transported from the leaves to the shoot apical meristem through the phloem sieve elements. This long-distance movement is a critical step in the systemic signaling of the flowering process. The phloem provides an efficient route for the protein to travel from the site of its synthesis in the source leaves to its site of action.

93. (C) FD
Upon arriving at the shoot apical meristem, the FT protein interacts directly with a basic leucine zipper transcription factor called FD. FD is expressed specifically in the cells of the meristem. The formation of the FT/FD protein complex is a necessary step for activating the downstream genes that establish floral identity, effectively translating the mobile leaf signal into a localized response.

94. (A) APETALA1 (AP1)
The FT/FD protein complex formed in the shoot apical meristem directly activates the transcription of floral meristem identity genes, most notably APETALA1. AP1 is essential for specifying that the newly formed primordia will develop into flowers rather than leaves. This activation marks the transition from the vegetative state to the reproductive state, leading to the actual formation of floral structures.

95. (C) It interacts with specific phloem-mobile scaffolding proteins.
The symplastic movement of the FT protein from companion cells into the phloem sieve elements is facilitated by its interaction with specific phloem-mobile scaffolding proteins. These interactions help the FT protein navigate the plasmodesmata and ensure its efficient transport through the vascular system. This specialized mechanism allows the relatively small protein to act as a systemic signal despite the cellular barriers.

96. (A) TERMINAL FLOWER 1 (TFL1)
TERMINAL FLOWER 1 is a homologous gene that acts as an antagonist to FT, generally repressing flowering and maintaining the vegetative state of the meristem. While FT promotes the transition to reproductive growth, TFL1 ensures that some meristems remain vegetative, which is important for indeterminate growth. The balance between FT and TFL1 activity determines the overall plant architecture and flowering.

97. (D) Substitution of a single critical amino acid in the binding pocket.
Despite having opposite functions in the regulation of flowering, the FT and TFL1 proteins are structurally very similar. The fundamental difference in their activity is primarily attributed to the substitution of a single critical amino acid in the protein's binding pocket. This small change alters how the proteins interact with molecular partners, determining whether the complex activates or represses the transition to flowering.

98. (B) Perception of the environmental cue in one organ (leaf) generates a mobile signal that triggers a response in a distant organ (meristem).
Systemic signaling in flowering refers to the phenomenon where the perception of environmental cues occurs in one organ, typically the leaf, but triggers a response in a distant organ, the shoot apical meristem. This process involves the generation of a mobile signal, like the FT protein, that travels through the vascular system to coordinate development across the entire plant body.

99. (B) The plant will flower without needing the photoperiodic signal in the leaf.
If the FT gene is genetically modified to be expressed directly in the meristem under a meristem-specific promoter, the plant will flower without needing a photoperiodic signal in the leaves. This is because the floral stimulus no longer needs to be perceived and transported from the foliage. The direct production of FT in the apex bypasses the normal environmental sensing mechanism.

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118. (A) I, II and IV
Vernalization prevents premature flowering during autumn and involves the cold-induced gene VIN3, which helps assemble the PRC2 complex at the FLC locus. The suppression of FLC is a classic example of mitotic cellular memory, as the silenced state is passed on through cell divisions. However, vernalization is generally perceived by hydrated, metabolically active tissues or imbibed seeds rather than dry seeds.

119. (D) Seed germination (imbibed seed stage) as well as the vegetative phase.
Some plants, such as winter wheat, have the ability to perceive the vernalization signal during both the early stages of seed germination and the later vegetative phase. This flexibility allows the plant to start counting the duration of cold as soon as it begins to grow. This ensures that even if the winter is short, the cold requirement can still be met.

120. (B) II
The statement that FLC is a floral activator is incorrect; FLC is actually a major floral repressor. Devernalization can indeed occur if cold treatment is followed immediately by high temperatures, and cool temperatures are typically required for several weeks. FLC also correctly encodes a MADS-box transcription factor that plays a central role in the molecular regulation of the transition from vegetative growth.

121. (C) Nitrogen-fixation pathway
While nitrogen availability can influence the timing of flowering, the nitrogen-fixation pathway is not recognized as a primary genetic pathway specifically dedicated to the control of flowering time. In contrast, the photoperiodic, vernalization, and gibberellin pathways are well-characterized molecular networks that integrate environmental and internal signals to precisely regulate the developmental switch from vegetative growth to the initiation of floral primordia.

122. (B) Repressing FLC expression via RNA processing and chromatin modification.
The autonomous flowering pathway promotes the transition to reproductive growth independently of environmental signals by repressing the expression of the floral repressor FLC. This pathway utilizes various molecular mechanisms, including RNA processing and chromatin modification, to keep FLC levels low. By reducing the inhibitory effect of FLC, the autonomous pathway ensures that the plant will eventually flower even without inductive photoperiods.

123. (C) Autonomous
The genes FCA, FY, and FPA are key components of the autonomous flowering pathway. These genes encode proteins involved in RNA binding and processing, which function to post-transcriptionally regulate the levels of the floral repressor FLC. By ensuring that FLC expression remains low, these genes allow the plant to flower based on its internal developmental state, providing a robust reproductive mechanism.

124. (D) Gibberellin (GA) pathway
Under strictly non-inductive short-day conditions, wild-type Arabidopsis depends almost entirely on the gibberellin pathway to eventually trigger the transition to flowering. In the absence of photoperiodic induction, gibberellins act to up-regulate the expression of floral meristem identity genes like LEAFY. This ensures that the plant completes its life cycle even when environmental cues are not optimal, highlighting reproductive flexibility.

125. (A) III, I, IV, II
The hierarchical sequence of flowering regulation in Arabidopsis begins with upstream regulators like CONSTANS. CO activates the expression of the mobile signal FLOWERING LOCUS T in the leaves. FT then moves to the meristem and activates the floral integrator SOC1. Finally, these signals converge to activate downstream floral meristem identity genes such as APETALA1, which physically initiate the formation of flowers.

126. (A) FT and SOC1
FLOWERING LOCUS T and SUPPRESSOR OF OVEREXPRESSION OF CO 1 are widely considered the central floral integrators in the plant flowering network. These two genes receive and integrate signals from all the major flowering pathways, including the photoperiodic, vernalization, and gibberellin pathways. Their activation marks the final convergence of various internal and external cues, leading directly to reproductive development.

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109. (C) An anti-gibberellin growth retardant (e.g., paclobutrazol)
If a grower wishes to chemically mimic the compacting effect of a negative DIF, they would most likely apply an anti-gibberellin growth retardant. These compounds work by inhibiting the biosynthesis of gibberellins, the same hormonal pathway affected by diurnal temperature fluctuations. This reduces internode elongation and results in shorter, sturdier plants, similar to results achieved through precise temperature management.

110. (A) I and II
A positive DIF generally increases stem elongation, while a negative DIF decreases it. These responses are well-documented in many plant species and are widely used in horticulture to control growth. While the magnitude of the response can be influenced by absolute temperatures, the relative difference between day and night remains the primary driver for regulating internode length and overall stem height.

111. (C) Exposure to a prolonged period of cold temperatures.
Vernalization is the process where flowering is promoted or induced by exposure to a prolonged period of low temperatures. This physiological requirement ensures that plants do not flower prematurely during the warm days of autumn and instead wait until they have survived the winter. This mechanism is common in winter annuals and biennials, allowing them to synchronize their reproduction with spring.

112. (C) Shoot apical meristem and dividing cells
The shoot apical meristem and other regions with actively dividing cells are the primary sites for the perception of cold temperatures during vernalization. Unlike photoperiodism, which is perceived in the leaves, the vernalization signal is localized to the growing tips of the plant. This ensures that the meristem itself is directly programmed to switch from vegetative to reproductive growth once required.

113. (C) FLOWERING LOCUS C (FLC)
In Arabidopsis thaliana, the requirement for vernalization is primarily maintained by the high expression of the FLOWERING LOCUS C gene. FLC acts as a potent floral repressor, preventing the transition to reproductive growth by silencing genes like FT and SOC1. For flowering to occur, FLC expression must be suppressed, a process triggered by prolonged cold temperatures experienced during the winter months.

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114. (A) Epigenetic silencing of the FLC locus.
During the process of vernalization, prolonged exposure to cold leads to the epigenetic silencing of the FLC locus. This suppression is not a result of DNA sequence changes but rather involves modifications to the chromatin structure. As FLC expression decreases, its inhibitory effect on the flowering pathway is removed, allowing the plant to respond to other cues, such as increasing day length.

115. (C) Histone H3 lysine 27 trimethylation (H3K27me3) via PRC2
The repressed state of the FLC gene is maintained through the winter and after the return to warm temperatures via histone H3 lysine 27 trimethylation. This specific modification is carried out by the Polycomb Repressive Complex 2. This epigenetic mark creates a stable, inheritable state of gene silencing, providing a cellular memory of the winter that allows flowering only when appropriate.

116. (C) It acts as a dominant activator of FLC, creating the vernalization requirement.
The gene FRIGIDA plays a critical role in establishing the vernalization requirement in winter-annual accessions of Arabidopsis. FRI acts as a dominant activator of FLC expression, ensuring that FLC levels remain high and prevent flowering before winter. Accessions lacking a functional FRI gene typically behave as summer annuals, flowering rapidly without the need for a prolonged cold treatment because FLC levels are low.

117. (B) It is erased, resetting the high FLC expression level in the next generation.
The epigenetic silencing of FLC achieved during vernalization is erased during the processes of meiosis and gametogenesis. This resetting ensures that the high expression of FLC is restored in the next generation, reinstating the vernalization requirement for the offspring. This cycle is essential for winter annuals, ensuring each new generation must experience its own winter before successfully transitioning to flowering.

allow for occasional outcrossing, which introduces genetic diversity and promotes the long-term adaptive potential of the plant population.

136. (A) Temporal separation of pollen release and stigma receptivity.
Dichogamy is a mechanism that promotes outcrossing by the temporal separation of pollen release and stigma receptivity within a single flower or plant. Either the pollen is shed before the stigma is receptive, or the stigma matures before the pollen is released. This separation prevents self-pollination and encourages the transfer of pollen between different individuals, thereby increasing genetic variation.

137. (D) SSR (Simple Sequence Repeats / Microsatellites)
SSRs are highly effective molecular markers for distinguishing between self-pollinated and cross-pollinated progeny. Their codominant nature and high levels of polymorphism allow researchers to clearly identify maternal and paternal alleles in the offspring. This provides precise data for calculating outcrossing rates and understanding mating systems, which is essential for both conservation biology and plant breeding programs in various species.

138. (B) High rates of self-fertilization (autogamy).
In population genetics, an excess of homozygotes relative to the expectations of the Hardy-Weinberg equilibrium typically indicates high rates of self-fertilization. Since selfing involves the fusion of gametes from the same individual, it leads to a systematic increase in homozygosity across the genome in each successive generation. This pattern is a hallmark of inbreeding and can estimate self-pollination levels.

139. (D) Spatial, morphological separation of anthers and stigmas within a flower.
Herkogamy is an anatomical adaptation that prevents self-pollination through the spatial and morphological separation of anthers and stigmas within a flower. By placing these organs in different positions, the plant reduces the likelihood of its own pollen reaching its own stigma. This physical barrier promotes outcrossing, as pollinators are more likely to transfer pollen from different individuals during foraging.

140. (A) Both A and R are true and R is the correct explanation of A.
Inbreeding depression is a significant evolutionary constraint on autogamous mating strategies, which involve continuous self-fertilization. This process increases the homozygosity of deleterious recessive alleles that are normally masked in a heterozygous state. As these harmful alleles become expressed, the overall fitness and vigor of the offspring often decrease, creating selective pressure that favors the maintenance of outcrossing mechanisms.

141. (B) The pollen coat (pollenkitt) interacting with the stigma pellicle.
The initial adhesion of a pollen grain to a dry stigma is primarily mediated by the interaction between the pollen coat and the proteinaceous pellicle on the surface of the stigma papillae. This rapid and specific binding is the first step in the recognition process between male and female tissues. This ensures that only compatible pollen grains from the correct species remain attached.

142. (C) It is covered by a copious surface secretion of lipids, proteins, and carbohydrates at maturity.
A wet stigma is characterized by being covered with a copious surface secretion at maturity. This exudate typically contains a complex mixture of lipids, proteins, and carbohydrates. Unlike dry stigmas, which have minimal surface fluid, wet stigmas provide a liquid medium that facilitates pollen adhesion, hydration, and germination. This type of stigma is common in many families, such as the Solanaceae.

143. (D) From the stigma papillae, moving across the contact zone.
During compatible pollen-stigma interactions on a dry stigma, the water required for the hydration of the dehydrated pollen grain originates from the stigma papillae. Upon successful recognition, water is actively transported from the papilla cell, across the contact zone, and into the pollen grain. This highly regulated hydration process is a critical checkpoint that ensures only compatible pollen can proceed.

144. (A) Apical tip
The growth of the pollen tube is highly polarized and is strictly restricted to the apical tip. This process involves the continuous delivery of vesicles containing new cell wall materials and membrane components to the very end of the

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to ethylene. In response to ethylene, these cells synthesize cell wall-degrading enzymes like cellulase and polygalacturonase. These enzymes break down the tissues, leading to the physical separation and fruit drop.

200. (B) Sink size multiplied by sink activity.
In plant physiology, sink strength is mathematically described as the product of sink size and sink activity. Sink size refers to the total biomass of the sink organ, while sink activity represents the rate of uptake of photoassimilates per unit of biomass. Understanding sink strength is crucial for studying how plants distribute resources among competing organs, which determines overall growth and yield.

201. (C) Produce functional pollen.
Cytoplasmic Male Sterility is a maternally inherited trait where a plant is unable to produce functional pollen, while its female reproductive organs remain perfectly fertile. This condition occurs due to defects in the mitochondrial genome that specifically affect the development of the male gametophyte. CMS is widely used in agriculture to create hybrid seeds without manual emasculation, making production more efficient.

202. (C) Mitochondrion
The genetic determinants responsible for Cytoplasmic Male Sterility are primarily located within the mitochondrial genome. Although most of a plant's genetic information is in the nucleus, mitochondria possess their own DNA that is typically inherited only from the maternal parent. Anomalies in this DNA can interfere with the high energy demands of pollen development, leading to male sterility while leaving female fertility unaffected.

203. (D) Extensive genomic rearrangements within mitochondrial DNA.
The molecular basis of CMS usually involves the expression of anomalous, chimeric open reading frames. These unique genetic sequences are typically generated by extensive and spontaneous rearrangements within the mitochondrial DNA. These rearrangements can fuse parts of normal genes with non-coding sequences, creating proteins that interfere with mitochondrial function during energy-intensive pollen development, ultimately leading to the failure of microspore maturation.

204. (A) urf13 (T-urf13)
The Texas cytoplasm male sterility in maize is caused by a specific chimeric mitochondrial gene known as T-urf13. This gene encodes a unique protein that inserts itself into the inner mitochondrial membrane. During pollen development, the expression of T-urf13 leads to mitochondrial dysfunction and tapetal cell death, resulting in male sterility. This system was extensively used until a major disease outbreak.

205. (A) II, I, III, IV
In a typical CMS system, the process of pollen abortion begins with the transcription of the chimeric mitochondrial ORF. This is followed by the accumulation of the resulting cytotoxic chimeric protein within the mitochondria. This protein causes the premature programmed cell death of the tapetum tissue. Without support from the tapetum, the microspores eventually starve and degrade, leading to sterile, non-functional pollen.

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206. (D) T-toxin from Bipolaris maydis (Southern corn leaf blight)
The T-urf13 protein responsible for CMS-T in maize also made the plants highly susceptible to the T-toxin produced by the fungus Bipolaris maydis. The T-toxin specifically binds to the T-urf13 protein in the mitochondrial membrane, creating pores that lead to cell death. This dual toxicity resulted in a massive agricultural disaster, highlighting the risks of using single cytoplasmic sources.

207. (B) It allows for cost-effective hybrid seed production without manual emasculation.
CMS is an extremely valuable tool in commercial agriculture because it allows for the cost-effective production of hybrid seeds on a large scale. By using male-sterile female lines, breeders can ensure that all seeds produced are the result of cross-pollination by a chosen male parent. This eliminates the need for labor-intensive manual emasculation, making hybrid technology accessible for many important crops.

208. (C) Tapetum
In many CMS systems, the physiological defect leading to sterility is physically manifested as the malfunctioning of the tapetum, which is the innermost layer of the anther wall. The tapetum provides essential nutrients for developing pollen grains. When mitochondrial dysfunction occurs

154. (C) S-RNase (Ribonuclease)
The GSI system in the Solanaceae family relies on the activity of S-RNase, which is the female determinant secreted into the extracellular matrix of the style. These ribonucleases are highly polymorphic and are encoded by the S-locus. During pollen tube growth, S-RNases from the style are taken up by the tube. If the S-allele of the RNase matches the pollen, it triggers rejection.

155. (D) Degrading pollen tube ribosomal RNA to arrest translation and growth.
During the self-incompatibility response in Solanaceae, if a matching S-RNase enters the pollen tube, it functions as a cytotoxin by degrading the pollen tube's ribosomal RNA. This destruction of the translational machinery effectively arrests protein synthesis and halts the growth of the pollen tube. This mechanism prevents the tube from reaching the ovary, ensuring that self-fertilization does not occur in these species.

156. (D) At the stigma surface, preventing pollen hydration or initial germination.
In the Brassicaceae family, the sporophytic self-incompatibility response occurs very rapidly, typically right at the surface of the stigma papillae. If the pollen is recognized as incompatible, the stigma prevents it from hydrating or initiating germination. This early checkpoint is a highly efficient way to block self-pollen before it can even begin to grow a tube, saving resources for successful reproductive attempts.

157. (A) SCR (or SP11)
The male determinant in the Brassicaceae self-incompatibility system is a small, cysteine-rich peptide known as SCR or SP11. This protein is located in the pollen coat and is derived from the paternal tapetum tissue. When the pollen grain lands on a stigma, the SCR peptide is released and interacts with the specific receptor on the surface of the stigma papillae, initiating recognition.

158. (A) Autophosphorylation of the SRK intracellular kinase domain.
In the Brassicaceae SSI system, the rejection response is triggered when the SCR ligand binds to the S-locus receptor kinase on the stigma papillae. This binding induces the autophosphorylation of the intracellular kinase domain of the SRK protein. The resulting phosphorylation cascade within the stigma cell leads to the inhibition of pollen hydration, effectively preventing self-pollination at the interface between tissues.

159. (D) Tightly linked, co-segregating genes encoding distinct male and female determinant proteins.
Although often referred to as a single locus, the S-locus actually consists of at least two tightly linked, co-segregating genes. One gene encodes the male determinant and the other encodes the female determinant. These genes must be inherited together as a functional unit to ensure that the recognition system remains specific and reliable across generations within a plant population during its evolution.

160. (A) IV, II, III, I
The process of self-incompatibility rejection in Brassicaceae begins with the deposition of pollen on the stigma. The SCR peptide from the pollen then binds to the SRK receptor on the stigma surface. This interaction triggers a phosphorylation signaling cascade within the stigma papillae. Finally, this intracellular signal leads to the inhibition of pollen hydration, preventing the self-pollen from germinating and fertilization.

161. (C) Ovary
Anatomically, a true fruit is defined as the product of the post-fertilization growth and maturation of the ovary. While other floral parts like the receptacle can sometimes contribute to the final structure, it is the ovary wall that develops into the pericarp, which encloses the seeds. This transformation is driven by a complex interplay of hormonal signals that coordinate growth and tissue differentiation.

162. (C) Rapid cell division
The initial phase of fleshy fruit development is characterized primarily by a period of rapid cell division. During this stage, the number of cells in the ovary wall increases significantly, establishing the structural framework for the future fruit. This phase is typically short and is followed by a much longer period of cell expansion, which accounts for most of the final volume and mass.

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growing tube. This specialized growth mechanism allows the pollen tube to rapidly elongate and navigate through the tissues of the style to reach the ovary.

145. (D) Calcium ions ($Ca^{\{2+\}}$)
Tip growth in pollen tubes is fundamentally driven by a localized and steeply increasing gradient of calcium ions. The highest concentration of calcium is found at the extreme apex of the tube. This gradient regulates the cytoskeleton and directs the fusion of secretory vesicles with the plasma membrane. Maintaining this calcium oscillation is essential for the rapid and directed elongation of the tube.

146. (C) Pectins
At the extreme apex of the growing pollen tube, de-esterified pectins are rapidly synthesized and deposited to form a flexible cell wall. These pectins allow for the expansion and elongation of the tip while providing enough structural integrity to withstand internal turgor pressure. As the tube elongates, these pectins are often cross-linked by calcium ions in older wall sections for support.

147. (D) Callose plugs
As the pollen tube elongates through the style, it periodically deposits callose plugs to isolate the older, non-functional sections of the tube from the active tip. This ensures that the cytoplasm and the male gametes remain concentrated at the growing apex. These plugs also help maintain the high internal turgor pressure required to drive the rapid tip growth of the pollen tube.

148. (A) I, II and IV
Pollen tube guidance involves multiple mechanisms, including mechanical support from the transmitting tissue and the action of LURE peptides as synergid-secreted attractants. GABA gradients within the pistil also contribute to the initial directionality of tube growth. However, the pollen tube does not directly enter the egg cell; it typically enters one of the synergid cells where it ruptures for release.

149. (C) Chemotropism
The process by which the pollen tube is attracted towards the female gametophyte is a classic example of chemotropism. This directed growth is mediated by chemical gradients of signaling molecules, such as small peptides and ions, secreted by the tissues of the ovule and the synergid cells. These chemical cues guide the pollen tube along its final path to ensure successful fertilization.

150. (A) I, II, III and IV
Pollen-pistil interactions involve several critical steps, with dry stigmas generally regulating hydration more stringently than wet stigmas. Dry stigmas possess a proteinaceous pellicle that is vital for initial recognition, acting as the first checkpoint for compatibility. On wet stigmas, the exudates often contain lipids that help reduce water evaporation and provide a favorable environment for the germination of compatible pollen.

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151. (D) Prevent inbreeding and promote outcrossing by rejecting self-pollen.
Self-incompatibility is a sophisticated genetic mechanism used by many angiosperms to prevent self-fertilization and encourage outcrossing. By recognizing and rejecting their own pollen, plants avoid the negative consequences of inbreeding depression and increase the genetic diversity of their offspring. This system ensures that fertilization only occurs between individuals with different genotypes, thereby enhancing the long-term adaptive potential of the plant population.

152. (D) Diploid genotype of the paternal plant that produced the pollen.
In Sporophytic Self-Incompatibility, the compatibility phenotype of the pollen grain is determined by the diploid genotype of the paternal plant that produced it. This occurs because the S-determinants are deposited onto the pollen surface from the maternal tapetum during development. Consequently, all pollen grains from a single plant behave identically, regardless of their own haploid S-allele, according to the parent genotype.

153. (D) Single haploid S-allele matches either of the two S-alleles in the diploid pistil.
Gametophytic Self-Incompatibility implies that the compatibility of a pollen grain is determined by its own individual haploid S-genotype. If the single S-allele carried by the pollen matches either of the two S-alleles present in the diploid tissues of the pistil, the pollen will be recognized as self and rejected. This system allows for more complex patterns of compatibility compared to sporophytic systems.

172. (D) Endosperm
In the process of double fertilization, the central cell of the embryo sac is fertilized by one of the two sperm cells, leading to the development of a triploid tissue known as the endosperm. This unique tissue is specialized for the storage of nutrients, such as starch, proteins, and lipids. It serves as the primary source of energy and building materials for the embryo.

173. (B) To serve as a nutritive tissue supplying the developing or germinating embryo.
The primary role of the endosperm in seed biology is to serve as a nutritive tissue that supplies the developing and germinating embryo with essential nutrients. By accumulating and then breaking down storage reserves, the endosperm provides the energy and carbon skeletons needed for the embryo to grow until it becomes photosynthetically active. These nutrients are sometimes transferred to cotyledons before maturity.

174. (A) Late Embryogenesis Abundant
LEA stands for Late Embryogenesis Abundant, referring to a large group of proteins synthesized in high quantities during the later stages of seed maturation. These proteins are highly hydrophilic and remain stable even under conditions of extreme dehydration. Their expression is tightly regulated by developmental programs, ensuring that the seed is prepared to survive the severe desiccation that occurs as it reaches maturity.

175. (D) Protecting cell structures from desiccation and preventing protein aggregation.
The physiological function of LEA proteins is generally to protect cellular structures and proteins from the damaging effects of desiccation. They act as molecular chaperones that prevent the aggregation of other proteins and stabilize membranes during the loss of water. By maintaining the integrity of cell components in a dehydrated state, LEA proteins ensure the seed remains viable and successfully resumes activity.

176. (C) Abscisic acid (ABA)
Abscisic acid is a critical phytohormone that reaches peak levels during the maturation phase of seed development. It is absolutely required for inducing primary dormancy and promoting desiccation tolerance. ABA prevents precocious germination of the embryo while on the parent plant and coordinates the synthesis of protective molecules. The balance between ABA and gibberellins ultimately determines whether a seed remains dormant or germinates.

177. (C) Protein bodies (specialized vacuoles)
Seed storage proteins, such as globulins and prolamins, are synthesized on the rough endoplasmic reticulum and packaged into specialized vacuoles known as protein bodies. These structures provide a secure and organized environment for storing the massive amounts of protein required to support the germinating embryo. During germination, enzymes are activated to break down these proteins into amino acids for the growing seedling.

178. (A) Both A and R are true and R is the correct explanation of A.
Orthodox seeds are characterized by their ability to survive extreme drying to very low moisture contents. This desiccation tolerance is achieved through the accumulation of non-reducing sugars and LEA proteins during the maturation phase. These molecules create a glassy state within the cytoplasm, which is a highly viscous solid. This state stabilizes cellular membranes and proteins, allowing the seed to remain viable.

179. (B) Do not acquire desiccation tolerance and die if dried below critical moisture levels.
Recalcitrant seeds differ from orthodox seeds primarily because they do not acquire desiccation tolerance during their development. They remain metabolically active and must maintain a high moisture content to stay viable. If these seeds are dried below a critical level, they suffer irreversible damage and die. Consequently, recalcitrant seeds cannot be stored using traditional methods and typically germinate shortly after being shed.

180. (C) A is true but R is false.
Vivipary, which is the precocious germination of seeds while still attached to the parent plant, is commonly observed in mutants that are deficient in abscisic acid. This occurs because ABA is essential for establishing and maintaining seed dormancy. However, the reason provided is false; ABA's primary role in mid-embryogenesis is not to promote cell division, but rather to inhibit it and promote storage.

181. (C) Physiological fruit drop
Seed and fruit abortion is a natural mechanism used by plants to regulate their crop load according

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alternative pathways that help the mitochondria overcome the stress caused by chimeric proteins.

218. (D) It promotes cleavage of the atp6-orf79 mRNA to prevent toxic ORF79 translation.
In the CMS-Boro II system of rice, the restorer gene Rf1a functions by promoting the specific cleavage of the atp6-orf79 mitochondrial mRNA. The orf79 segment of this transcript is responsible for producing the toxic protein that causes male sterility. By facilitating the degradation of this polycistronic message, the Rf1a protein prevents the accumulation of the ORF79 toxin, restoring male fertility.

219. (B) Intracellular genomic coevolution (or "arms race")
The relationship between the emergence of novel CMS-inducing mitochondrial mutations and the subsequent evolution of nuclear restorer genes is an example of intracellular genomic coevolution. This arms race between the two genomes within the same cell occurs as the nucleus evolves mechanisms to suppress the deleterious effects of mitochondrial variants. This dynamic process has led to incredible diversity in systems.

220. (B) An Rf restorer line is NOT required, as fertility in the F1 is unnecessary for harvest.
For crops where the economic product is a vegetative part, such as onions or cabbage, an Rf restorer line is not required in the hybrid production process. Since the final harvest does not depend on the production of seeds or fruit, the male sterility of the F1 hybrid is not a disadvantage. Breeders only need the A-line and B-line for production.

221. (B) The F1 hybrid demonstrates superior phenotypic traits (e.g., yield, growth rate) compared to the average or the best of its homozygous parents.
Heterosis, commonly known as hybrid vigor, is the phenomenon where the F1 hybrid offspring demonstrate superior phenotypic traits compared to the average or the best of its homozygous parents. These traits often include increased yield, faster growth rates, and greater tolerance to environmental stress. Heterosis is a fundamental concept in plant breeding and has driven massive increases in agricultural productivity.

222. (B) The masking of deleterious recessive alleles from one parent by dominant favorable alleles from the other parent.
The Dominance Hypothesis proposes that heterosis results from the masking of deleterious recessive alleles from one parent by dominant favorable alleles from the other parent. In homozygous parental lines, these harmful recessive alleles are expressed and reduce vigor. When lines are crossed, the hybrid becomes heterozygous, allowing dominant alleles to hide negative effects, leading to an increase in overall fitness.

223. (A) The heterozygous state (Aa) at a single locus is inherently physiologically superior to both homozygous states (AA or aa).
The Overdominance Hypothesis suggests that heterosis occurs because the heterozygous state at a single gene locus is inherently physiologically superior to both of the homozygous states. According to this model, the combination of two different alleles provides a broader range of function than either allele alone. This inherent superiority of the heterozygote contributes to the enhanced performance seen in hybrid organisms.

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224. (B) Non-allelic gene interactions where the effect of one gene locus masks or modifies the effect of another.
Epistasis is a major genetic contributor to heterosis and refers to non-allelic gene interactions where the effect of one gene locus masks or modifies the effect of another. In the context of hybrid vigor, favorable epistatic interactions between genes from different parents can lead to synergistic effects that exceed simple additive benefits. These complex interactions are critical parts of hybrid performance.

225. (B) Enhanced energy use efficiency and improved carbon assimilation.
At the physiological and metabolic level, heterosis is frequently associated with enhanced energy use efficiency and improved carbon assimilation. Hybrids often exhibit higher photosynthetic rates and more efficient nutrient uptake than their parental lines. This metabolic superiority provides the hybrid with more resources for development, resulting in increased biomass and yield. These efficiency gains are central to the success of hybrid varieties.

of an abscission layer. The June drop in apples is a well-known example of this process. However, ethylene application does not suppress abortion; instead, it typically promotes it.

191. (C) Synthetic auxins or ethylene-releasing compounds.
To chemically thin heavy crop loads and induce controlled fruit abortion, orchardists often apply synthetic auxins or ethylene-releasing compounds early in the season. These chemicals disrupt the natural hormonal balance and increase the rate of abortion in a portion of the young fruits. This management practice ensures that the remaining fruits grow larger and have better quality, preventing the tree from being overstressed.

192. (C) Synthetic auxins (to counteract ethylene sensitivity in the abscission zone)
If a grower wants to prevent pre-harvest fruit drop in mature fruits like apples, they might apply exogenous synthetic auxins. These compounds work by counteracting the plant's increasing sensitivity to ethylene in the abscission zone as the fruit ripens. By maintaining a high level of auxin-like activity at the fruit stalk, the activation of cell wall-degrading enzymes is delayed effectively.

193. (B) Promote berry enlargement and rachis elongation in stenospermocarpic fruits.
Exogenous application of gibberellic acid is a standard commercial practice in the production of seedless grapes. Since these stenospermocarpic fruits lack developing seeds that would normally produce GA, they tend to stay small. Applying GA helps to promote berry enlargement and elongates the rachis, which provides more room for the berries to grow and improves the overall appearance of the clusters.

194. (A) Sucrose, amino acids, and precise hormonal balances.
Rescuing aborting interspecific hybrid embryos involves excising the young embryo before it dies and cultivating it on a specialized tissue culture medium. This medium must be rich in sucrose to provide energy and contain essential amino acids and precise balances of phytohormones to substitute for the missing endosperm. This technique is a powerful tool for breeders to create new hybrid varieties.

195. (B) Pruning or mechanically thinning a portion of the flowers/young fruits.
Pruning or mechanically thinning a portion of the flowers or young fruits can physically reduce sink competition within the plant. By decreasing the total number of developing offspring, more photoassimilates become available for the remaining fruits. This intervention effectively decreases the natural abortion rate of those fruits and often results in larger, higher-quality produce, which is a common management strategy.

196. (B) Inhibiting ethylene action or synthesis to delay abscission zone activation.
The application of anti-ethylene compounds like 1-MCP or AVG can influence fruit drop by either inhibiting the action of ethylene or blocking its biosynthesis. By delaying the activation of the abscission zone, these chemicals can prevent premature fruit drop under stressful conditions or during final ripening. This technology is widely used in post-harvest management and to extend the window for harvesting.

197. (D) Boron and Calcium
Deficiencies in boron and calcium are strongly correlated with increased flower and fruit abortion. Both nutrients play critical roles in maintaining cell wall stability and are essential for proper pollen tube growth and fertilization. Without adequate levels of these elements, reproductive tissues cannot develop correctly, leading to failed fruit set and embryo death. Ensuring availability is vital for achieving high efficiency.

198. (B) Increasing local sink strength, enhancing the drawing power of assimilates to the fruit.
Exogenous application of cytokinins to developing fruits can mitigate abortion under stress by increasing the local sink strength of the fruit. Cytokinins enhance the ability of the fruit tissue to draw in photoassimilates and other nutrients from the rest of the plant. By ensuring a steady supply of energy during resource limitation, cytokinins help the fruit continue its development successfully.

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199. (A) II, IV, I, III
Normal fruit abscission begins with a reduction in the flux of auxin from the developing fruit to the pedicel. This decrease in auxin makes the cells in the abscission zone more sensitive

to available resources. This phenomenon, where immature fruits are shed, is often termed physiological fruit drop. By aborting some of its developing offspring, the plant can ensure that the remaining fruits have enough nutrients to reach full maturity and produce high-quality seeds for successful reproduction.

182. (B) High temperature stress during anthesis and early post-fertilization
High temperature stress during anthesis and early post-fertilization is a major environmental factor that frequently induces high rates of early fruit and seed abortion. Heat stress can damage pollen grains and disrupt the delicate hormonal balance required for fruit set. This results in failed fertilization or early embryo death, triggering abscission signaling pathways and leading to the significant loss of potential yield.

183. (C) Limited photoassimilates (carbohydrates) from source leaves
From a physiological standpoint, fruit abortion occurs because developing fruits are intense metabolic sinks that compete for a limited supply of photoassimilates from the source leaves. If the demand for carbohydrates exceeds current photosynthetic capacity, some fruits will not receive enough energy to continue development. This resource limitation triggers a signaling cascade that leads to abortion of the weakest sinks to save others.

184. (A) Vascular continuity and sink strength established by the earlier fruits.
Dominance among developing fruits on the same plant often leads to the abortion of later-set fruits. This is largely governed by the vascular continuity and superior sink strength established by the earlier-set fruits. These older fruits effectively monopolize the flow of nutrients and hormones, leaving the younger fruits with insufficient resources for growth. This hierarchy ensures that some offspring reach maturity.

185. (B) Seed abortion and subsequent fruit drop
Incomplete fertilization, often caused by poor pollen viability or failed pollen tube growth, leads directly to seed abortion and subsequent fruit drop. Since developing seeds are the primary source of the hormones required to maintain fruit growth, their failure to develop results in a drop in auxin levels. This hormonal shift activates the abscission zone in the fruit stalk, causing fruit loss.

186. (B) Ethylene
Ethylene is the primary hormone synthesized in the pedicel abscission zone in response to environmental stress or failed seed development. Its production triggers the activity of cell wall-degrading enzymes that cause the separation of cells and the eventual dropping of the fruit. Ethylene acts antagonistically to auxin; as the flow of auxin decreases, the tissue becomes more sensitive to ethylene signals.

187. (D) Fertilization occurs, but the embryos abort early, resulting in seedless fruits.
Stenospermocarpy is a specific biological condition where fertilization occurs normally, but the embryos abort shortly thereafter. Despite the loss of the embryos, the fruit continues to grow and reach maturity, resulting in a seedless or soft-seeded fruit. This phenomenon is commercially exploited in the production of table grapes. The early presence of the developing embryo provides enough initial hormonal stimulus for growth.

188. (A) I
The statement that abortion is always a pathological defect is incorrect; in many cases, selective seed abortion is an adaptive trait that allows plants to manage limited resources. Resource limitation is indeed a primary driver, and seeds with genetic anomalies often abort due to endosperm failure. Furthermore, the proper development of the endosperm is crucial for embryo survival, as it provides necessary nutrients.

189. (B) Seed abortion
Genetic incompatibilities between the maternal tissue and the endosperm can lead to post-zygotic reproductive isolation, frequently resulting in seed abortion. This often occurs in interspecific crosses where the genomes of the two parents are too divergent to coordinate the complex development of the endosperm. Without a functional endosperm to nourish it, the embryo fails to mature, acting as a barrier.

190. (A) I, II and IV
Fruit drop is often caused by high sink competition leading to assimilate starvation in weaker fruits. A decrease in the flux of endogenous auxin from the fruit to the pedicel promotes the formation

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in this high-energy-demand tissue, it undergoes premature degradation. This failure to support the microspores results in their abortion within the anther.

209. (B) Creation of non-specific pores causing a loss of membrane potential and ATP depletion.
The chimeric proteins associated with CMS typically insert themselves into the inner mitochondrial membrane, where they can create non-specific pores. These pores cause a loss of the electrochemical membrane potential, which is essential for ATP synthesis. This leads to severe depletion of cellular energy, particularly in the tapetum during microsporogenesis. This energetic failure ultimately triggers cell death, resulting in microspore abortion.

210. (B) 100% Male Sterile
Because CMS is maternally inherited through the mitochondria, if a CMS female parent is pollinated by a normal male fertile maintainer line, the resulting progeny will be 100% male sterile. The maintainer line is genetically identical in the nucleus but possesses normal, fertile cytoplasm. This crossing allows breeders to maintain and multiply the male-sterile female line for future hybrid seed production.

211. (D) Rf genes (Restorer of fertility)
Fertility restoration in CMS systems is achieved through the action of dominant nuclear genes known as Rf genes, which stands for restorer of fertility. When these genes are present in the nucleus of a CMS plant, they counteract the effects of the sterile cytoplasm and restore functional pollen production. This is essential for producing fertile F1 hybrids in many grain crops.

212. (B) Pentatricopeptide Repeat (PPR) proteins
Most classical Rf genes encode a specific class of RNA-binding proteins known as Pentatricopeptide Repeat proteins. These proteins are characterized by multiple tandem repeats of a conserved amino acid motif. PPR proteins are targeted to the mitochondria, where they bind to specific transcripts. In CMS systems, they target the anomalous transcripts that cause sterility, regulating their processing and ensuring normal development.

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213. (B) By binding to the anomalous CMS transcript and promoting its cleavage, degradation, or altering its translation.
Rf PPR proteins neutralize the male-sterile phenotype by binding to the anomalous CMS mitochondrial transcript. This binding can promote the cleavage or degradation of the transcript, or it can physically block its translation. By reducing the levels of the toxic chimeric protein, the Rf genes allow the mitochondria to function normally during pollen development. This molecular intervention restores male fertility effectively.

214. (C) N or S RfRf
In a three-line hybrid seed production system, the R-line or restorer line must carry dominant Rf genes to ensure the F1 hybrid is fertile. The genotype of the R-line is typically homozygous dominant at the restorer locus. It can have either normal or sterile cytoplasm, but it must be male fertile itself to provide pollen for the cross with the A-line.

215. (A) III, II, I
The three-line hybrid seed production process begins with the maintenance of the male-sterile A-line by crossing it with the fertile maintainer B-line. Next, the A-line is crossed with the restorer R-line to produce the F1 hybrid seeds. Finally, these F1 seeds are sold to farmers and grow into fertile plants that can produce a full crop of grain for harvest.

216. (D) They abort early at the uninucleate stage due to tapetal abnormalities.
In the CMS-WA system, which is used extensively in the production of hybrid rice, the developing microspores abort early at the uninucleate stage. This abortion is caused by severe abnormalities in the tapetal tissue, which fails to provide support for the young microspores. As a result, the anthers do not produce any viable pollen, making the system highly reliable for seed production.

217. (A) A mitochondrial aldehyde dehydrogenase.
While most restorer genes encode PPR proteins, the Rf2 gene in the maize CMS-T system is a notable exception. It encodes a mitochondrial aldehyde dehydrogenase enzyme. The Rf2 protein does not appear to directly regulate the CMS transcript; instead, it likely functions by detoxifying metabolic byproducts or providing

163. (D) Turgor pressure and the relaxation of cell wall extensibility.
Following the cell division phase, fruit size increases dramatically during the cell expansion phase. This growth is driven by turgor pressure acting against the cell walls, combined with the biochemical relaxation of cell wall extensibility. During this period, the cells undergo massive vacuolization and accumulate water and solutes, resulting in the characteristic fleshy texture and large size observed in many mature fruits.

164. (A) Auxins and Gibberellins
Developing seeds are a primary source of phytohormones, particularly auxins and gibberellins, which are essential for stimulating the initial growth and cell division of the surrounding ovary tissue. These hormones act as signals that coordinate the development of the fruit with the maturation of the seeds. If fertilization fails or seeds abort, the lack of these hormonal signals often leads to abscission.

165. (D) Development of a fruit without successful fertilization or seed formation.
Parthenocarpy refers to the development of a fruit without successful fertilization or the formation of seeds. This can occur naturally in some species or be induced through hormonal treatments. Parthenocarpic fruits are often highly desirable in agriculture because they are seedless. This process demonstrates that the signals for fruit growth can sometimes be uncoupled from the actual reproductive events in the ovules.

166. (C) Ethylene
Climacteric fruit ripening is defined by a distinct burst in cellular respiration and the autocatalytic synthesis of the gaseous hormone ethylene. This surge in ethylene production coordinates the various biochemical changes associated with ripening, such as softening and color change. Once triggered, the process becomes self-sustaining, allowing climacteric fruits to continue ripening even after they have been harvested from the parent plant.

167. (C) Strawberry
Strawberries are a classic example of non-climacteric fruits. Unlike climacteric fruits, they do not show a dramatic burst in respiration or ethylene production during the ripening process. Instead, their maturation is a more gradual event that typically requires the fruit to remain attached to the parent plant to reach full ripeness. Once harvested, strawberries do not continue to ripen significantly after removal.

168. (A) P-4, Q-3, R-2, S-1
Fruit ripening involves several coordinated biochemical changes. Softening is caused by the depolymerization of pectins by enzymes like polygalacturonase. Sweetening results from the breakdown of stored starch into simple sugars. Color changes occur as chlorophyll degrades and carotenoids are synthesized. Finally, the characteristic aroma develops through the synthesis of a variety of volatile organic compounds that attract seed dispersers to the plant.

169. (B) Push the embryo proper into the nutrient-rich endosperm and transfer nutrients.
During the early stages of seed development, the suspensor plays a vital role by physically pushing the embryo proper into the nutrient-rich endosperm tissue. It also serves as a conduit for the transfer of nutrients, hormones, and other essential molecules from the maternal tissues to the developing embryo. Although the suspensor is temporary, its function is critical for the initial establishment and growth.

170. (A) P-1, Q-3, R-2, S-4
Seed development begins with histodifferentiation, involving rapid cell division and the formation of the basic body plan. This is followed by the maturation phase, where the seed accumulates storage reserves like proteins and starch. Desiccation then occurs, reducing moisture content to prepare for dormancy. Finally, the process of germination culminates in radicle emergence, marking the start of a new plant life cycle.

171. (A) Embryo proper
In typical dicot embryogenesis, the first division of the zygote is asymmetric, producing a small apical cell and a larger basal cell. This division establishes the apical-basal axis of the future plant. The smaller apical cell subsequently undergoes a series of organized divisions to give rise to the embryo proper, while the larger basal cell develops into the suspensor which nourishes the embryo.

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226. (B) Non-additive gene expression and altered DNA methylation levels at specific loci.
Recent molecular studies suggest that heterosis may partly arise from non-additive gene expression patterns and altered DNA methylation levels in hybrids compared to their parents. These epigenetic changes can lead to the over-expression of growth-promoting genes. This complex regulation at the transcriptomic level allows hybrids to optimize their processes, contributing to superior phenotypic traits and vigor.

227. (C) Inbreeding depression occurs, leading to phenotypic segregation and vigor loss.
When superior F1 hybrids are allowed to self-pollinate to produce an F2 generation, inbreeding depression occurs. This leads to phenotypic segregation and a significant loss of vigor compared to the F1. As alleles segregate, many individuals in the F2 return to a homozygous state for deleterious recessive alleles. This reduction in performance is why farmers must purchase new hybrid seeds annually.

228. (B) Heterosis is strictly limited to cross-pollinated species and cannot occur in self-pollinated crops like rice.
The statement that heterosis is strictly limited to cross-pollinated species is incorrect; it also occurs and is successfully utilized in self-pollinated crops like rice. Commercial maize production does heavily rely on heterosis, and terms like standard heterosis have specific meanings. Furthermore, having a high general combining ability in parental lines is a crucial factor when developing vigorous and high-performing hybrid varieties.

229. (B) Mitochondrial complementation and enhanced respiratory efficiency in vitro.
Mitochondrial complementation and enhanced respiratory efficiency in vitro are sometimes used as early biochemical markers to predict the extent of heterosis in developing hybrids. When mitochondria from different parental lines are mixed, an increase in respiration can indicate a favorable interaction between their genomes. This physiological efficiency at the cellular level reflects the potential for overall hybrid vigor and superior performance.

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230. (A) I, III and IV
The dominance hypothesis of heterosis relies on the complementation of deleterious recessive alleles, while epistatic interactions involve synergistic effects between different gene loci. Heterosis also involves both additive and non-additive genetic variances. However, single-gene overdominance is not the sole cause of yield heterosis, as complex traits are governed by many genes and diverse genetic mechanisms.

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2001

20. Consider the following statements about growth indices:

I. RGR represents the increase in plant material per unit of material present per unit of time.
II. CGR can be estimated as the product of LAI and NAR.
III. SLA is the reciprocal of Specific Leaf Weight (SLW).
IV. LAI strictly measures the volume of the plant canopy.

Which of the above statements is/are correct?

(A) I, II and IV
(B) I, III and IV
(C) I, II and III
(D) II and IV

2013

21. Juvenility in perennial plants is primarily defined physiologically as the phase where the plant:

(A) Is incapable of responding to floral induction stimuli
(B) Possesses an optimal carbon-to-nitrogen ratio
(C) Produces only reproductive floral meristems
(D) Exhibits maximum resistance to abiotic stress

2004

22. Which of the following is a classic morphological marker of juvenility in English Ivy (Hedera helix)?

(A) Production of simple, entire leaves
(B) Erect stems and reproductive inflorescences
(C) Lobed leaves and creeping growth habit
(D) Complete absence of adventitious roots

2002

23. Phase change to maturity in woody perennials is generally associated with:

(A) A decline in rooting ability of stem cuttings
(B) An absolute increase in the synthesis of gibberellins in the apical meristem
(C) Enhanced production of adventitious roots
(D) Increased thorniness in species like Citrus

2007

24. What biochemical mechanism is frequently linked with the maintenance of the juvenile state in woody plants?

(A) Complete suppression of the primary auxin biosynthesis pathway
(B) Excessive accumulation of florigen within the apical tissues
(C) Reduced expression of vegetative growth and development genes
(D) High levels of endogenous gibberellins present in the plant

2003

25. Identify the correct statement regarding phase change in perennials.

(A) It occurs uniformly and simultaneously across all branches of a tree
(B) Lower parts of the tree trunk retain juvenile characteristics longer
(C) Maturation processes strictly prevent any vegetative growth from occurring
(D) The duration of juvenility is identical across all woody plant species

2009

26. Which of the following practices is most effective for accelerating the phase change from juvenility to maturity in seedling trees?

(A) Heavy application of exogenous gibberellic acid
(B) Growing plants under continuous low-light conditions
(C) Grafting juvenile seedling scions onto mature, flowering trees
(D) Subjecting the plants to severe water-logging stress

2008

27. The phenomenon of "topophysis" during asexual propagation of mature perennials refers to:

(A) Cuttings failing to root due to high endogenous abscisic acid levels
(B) The rapid transition of mature cuttings back to a truly juvenile state
(C) The geotropic bending of the root system in response to gravity signals
(D) Cuttings retaining the developmental phase of the source branch

2011

28. Which morphological trait is least relevant as an indicator of maturity in citrus seedlings?

(A) Presence of thorns
(B) Total lack of thorns
(C) Production of flowers
(D) Altered leaf shapes

2019

29. The biochemical basis of floral induction during phase change primarily requires the integration of:

(A) Stomatal closure and the secretion of root exudates
(B) Photoperiodic signals and internal developmental competence

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(C) Senescence
(D) Elongation

2017

10. Consider the following statements regarding secondary meristems:
I. They are responsible for the increase in girth of the plant.
II. Cork cambium is an example of a secondary meristem.
III. They are present in all monocot stems.
Which of the above statements is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I only

2019

11. Which mathematical formula correctly represents the Crop Growth Rate (CGR)?
(A) $\frac{\ln W_2 - \ln W_1}{t_2 - t_1}$
(B) $\frac{W_2 - W_1}{A_2 - A_1}$
(C) $\frac{A_2 - A_1}{t_2 - t_1}$
(D) $\frac{W_2 - W_1}{t_2 - t_1}$

2019

12. Leaf Area Index (LAI) is best defined as:
(A) Ratio of total leaf area to the ground area
(B) Ratio of total leaf biomass to specific weight
(C) Total leaf dry weight produced per ground area
(D) Photosynthetic efficiency of the entire canopy

2017

13. Specific Leaf Area (SLA) is an essential growth index calculated by dividing:
(A) Leaf dry mass by leaf area
(B) Leaf area by leaf dry mass
(C) Total plant dry weight by leaf area
(D) Ground area by total leaf area

2002

14. Net Assimilation Rate (NAR) is considered a measure of:
(A) Structural efficiency of primary root networks
(B) Average photosynthetic efficiency of leaves
(C) Rate of respiration per whole-plant dry weight
(D) Speed of essential nutrient uptake from soil

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2004

15. Relative Growth Rate (RGR) conceptually integrates which two physiological indices?
(A) NAR and Leaf Area Ratio (LAR)
(B) LAI and CGR
(C) SLA and Specific Leaf Weight (SLW)
(D) Crop Growth Rate and Harvest Index

2010

16. Which of the following conditions generally leads to a decline in Net Assimilation Rate (NAR) as a plant matures?
(A) Decreased specific leaf weight
(B) Enhanced root-to-shoot ratio
(C) Increased mutual shading of leaves
(D) Increased availability of soil nitrogen

2012

17. Identify the INCORRECT statement regarding growth indices.
(A) RGR is calculated on a logarithmic scale of plant dry weight.
(B) Optimal LAI maximizes canopy light interception without excessive shading.
(C) CGR typically reaches a peak during the maximum vegetative growth phase.
(D) SLA always increases steadily until the plant reaches complete senescence.

2021

18. An agronomist notices that despite a high LAI, the Crop Growth Rate (CGR) is declining. What is the most appropriate physiological explanation?
(A) The plant has shifted its metabolic resources to apomictic reproduction
(B) The specific leaf area index is increasing at an exponential rate
(C) Photosynthetic rates of lower leaves are below the compensation point
(D) Relative Growth Rate has significantly exceeded its theoretical maximum

2024

19. If a plant exhibits a high Leaf Area Ratio (LAR), it indicates that:
(A) The leaves are exceptionally thick, heavy, and dense
(B) A large proportion of the biomass is allocated to leaves
(C) The root system dominates the overall plant biomass ratio
(D) The plant is experiencing severe physiological water stress

Which of the above statements is/are correct?
(A) I and III
(B) II and III
(C) I and II
(D) I, II and III

2018

81. The driving force for the cohesion-tension mechanism is primarily generated by:
(A) Root pressure
(B) Capillary action in the phloem
(C) Metabolic energy in the stem
(D) Transpiration from the leaf surface

2022

82. Which property of water is essential for maintaining the continuous column of sap in xylem vessels?
(A) High specific heat
(B) Low viscosity
(C) Cohesive and adhesive forces
(D) Low surface tension

2012

83. The transition of water from the apoplast to the symplast at the root endodermis is critical because it allows the plant to:
(A) Speed up water uptake limitlessly
(B) Filter and selectively absorb ions
(C) Avoid using any metabolic energy
(D) Divert water directly to the phloem

2010

84. Identify the INCORRECT statement regarding the cohesion-tension mechanism.
(A) It requires a continuous water column from roots to leaves
(B) It operates under negative pressure (tension) in the xylem
(C) Evaporation from mesophyll cells creates the tension force
(D) It relies on active transport of water by xylem ATPases

2011

85. What causes the physical phenomenon of root pressure observed in some plants?
(A) Ion accumulation lowering osmotic potential
(B) Rapid transpiration rates during the day
(C) Condensation of water vapor in the canopy
(D) Freezing of water molecules in the soil

2005

86. Hydraulic architecture in woody perennials dictates that branch junctions generally possess:
(A) Wider xylem vessels than main stems
(B) Completely unobstructed water flow without any pits
(C) Increased hydraulic resistance compared to the main stem
(D) No functional xylem tissue

2023

87. Xylem vulnerability to cavitation is most highly correlated with:
(A) Conduit diameter and pit properties
(B) The thickness of the phloem layer
(C) Photosynthetic rate of mature leaves
(D) The presence of lenticels on bark

2021

88. Embolism in xylem vessels primarily disrupts the ascent of sap by:
(A) Poisoning the xylem sap with toxic gases
(B) Reversing the direction of root pressure
(C) Solidifying the sap into a viscous gel
(D) Breaking the water column with a bubble

2021

89. Stomatal regulation protects the hydraulic architecture of trees from catastrophic failure by:
(A) Remaining constantly open to cool the leaf
(B) Closing to prevent excessive xylem tension
(C) Pumping extra water out of the leaf actively
(D) Synthesizing lignin around the guard cells

2013

90. Consider the following statements about xylem cavitation:
I. Cavitation is the phase change of liquid water to vapor under high tension.
II. Freeze-thaw cycles can induce embolism in temperate trees.
III. Gymnosperms are generally more vulnerable to cavitation than angiosperms.
IV. Embolisms can sometimes be repaired via root pressure or local xylem refilling.
Which of the above statements is/are correct?
(A) I, II and IV
(B) I, III and IV
(C) II, III and IV
(D) I, II, III and IV

2001

91. The structural feature that limits the spread of air bubbles between adjacent xylem vessels is the:
(A) Sieve plate
(B) Casparian strip
(C) Apical meristem
(D) Pit membrane

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(C) Rapid synthesis of the secondary cell wall components
(D) Complete depletion of the total leaf carbohydrates

2021

30. Consider the following statements about juvenility and maturity:
I. Mature tissues generally lack the ability to form adventitious roots easily.
II. Rejuvenation can sometimes be achieved by serial micrografting.
III. Juvenility is strictly controlled by a single environmental trigger.
IV. The transition from juvenile to mature phase is known as ontogenetic aging.
V. Cone of juvenility describes the upper canopy of an adult tree.
Which of the above statements is/are INCORRECT?
(A) III and V
(B) I, II and IV
(C) II, III and V
(D) I and IV

2008

31. Apical dominance in plant shoots is primarily mediated by which pair of phytohormones acting in opposition?
(A) Auxin and Cytokinin
(B) Auxin and Gibberellin
(C) Ethylene and Abscisic Acid
(D) Cytokinin and Gibberellin

2013

32. What is the fundamental characteristic of indeterminate growth in a shoot?
(A) The apical meristem transforms into a terminal flower
(B) The shoot dies back completely at the end of every season
(C) Vegetative growth continues without terminal flower formation
(D) All internodes remain completely compressed throughout the lifecycle

2018

33. Episodic growth in woody perennials, such as mango, is characterized by:
(A) Continuous and uninterrupted elongation of shoots year-round
(B) Strict determination of shoot length by the photoperiod only
(C) Formation of a terminal bud immediately upon seed germination
(D) Alternating flushes of rapid extension and periods of rest

2014

34. Spurs in fruit trees like apple are best defined as:
(A) Fast-growing vegetative shoots that compete with the main trunk
(B) Adventitious roots emerging from the aerial branches
(C) Short, condensed shoots that primarily bear flowers and fruits
(D) Modified leaves adapted for mechanical defense

2002

35. Water sprouts are a type of shoot architecture characterized by:
(A) Highly productive and short-lived reproductive branches
(B) Upright vegetative shoots emerging from older wood
(C) Creeping horizontal stems facilitating vegetative spread
(D) Shoots modified strictly for water storage in arid regions

2011

36. Which structural mechanism primarily contributes to rhythmic growth patterns in tropical trees?
(A) Synchronized internal clocks regulating bud break
(B) Dependence on extreme seasonal freezing temperatures
(C) Lack of a distinct and active vascular cambium tissue
(D) Continuous overproduction of endogenous abscisic acid

2003

37. Identify the correct pair regarding shoot architecture.
(A) Monopodial growth - Terminal bud remains active and dominant
(B) Sympodial growth - Main axis continues indefinitely
(C) Determinate growth - Apical meristem remains permanently vegetative
(D) Plagiotropic shoot - Grows strictly vertically upright

2025

38. The physiological release of lateral buds from apical dominance typically occurs when:
(A) Cytokinin levels in the roots drop to zero
(B) Terminal buds begin to synthesize massive

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2023

58. By altering carbohydrate partitioning, summer pruning in fruit trees typically results in:
(A) Enhanced winter hardiness due to massive starch storage
(B) Uncontrollable spur growth during the autumn season
(C) Reduced tree size and improved fruit coloration
(D) Complete failure of the floral differentiation process

2007

59. The biochemical basis of dwarfing in fruit trees is often linked to the reduced transport or synthesis of which hormone?
(A) Ethylene
(B) Salicylic acid
(C) Jasmonic acid
(D) Gibberellin

2004

60. Choose the correct sequence of events leading to tree size reduction in high-density planting.
I. Increased inter-plant competition for light and nutrients
II. Decreased individual canopy volume
III. Altered root system architecture
IV. Mutual shading and hormonal redistribution
(A) I, IV, III, II
(B) I, III, IV, II
(C) IV, I, II, III
(D) III, II, I, IV

2011

61. Root restriction typically induces dwarfing by:
(A) Increasing the synthesis of root-derived cytokinins
(B) Limiting nutrient uptake and hormonal signaling
(C) Enhancing the total water potential of the shoot
(D) Promoting unrestricted and strong apical dominance

2012

62. High-density planting alters the physiological efficiency of an orchard primarily by:
(A) Decreasing the Leaf Area Index to near zero
(B) Maximizing light interception per unit area of land
(C) Promoting massive individual tree canopies
(D) Delaying the onset of reproductive maturity

2014

63. Which mechanism explains how dwarfing rootstocks control scion vigor?
(A) Partial restriction of water and hormone flow
(B) Excessive production of auxins passing up the graft union
(C) Enhanced translocation of gibberellins from roots to shoots
(D) Complete elimination of the functional phloem tissue

2016

64. Identify the correct statement regarding root restriction effects.
(A) It permanently prevents floral initiation
(B) It accelerates continuous vegetative flushing
(C) It shifts carbohydrate allocation to reproduction
(D) It eliminates the plant's sensitivity to ethylene

2015

65. The most significant physiological advantage of high-density planting is:
(A) Reduced requirement for canopy pruning
(B) Complete elimination of root competition
(C) Total avoidance of soil-borne diseases
(D) Early cropping and higher initial yields

NODIA

2002

66. A physiological disadvantage often associated with severe dwarfing is:
(A) Excessively deep taproot formation
(B) Overproduction of vegetative branches
(C) Poor anchorage needing structural support
(D) Delayed leaf fall during the winter

2012

67. The concept of "root volume limitation" is successfully applied in horticulture to:
(A) Maximize timber yield
(B) Induce precocity and manage canopy size
(C) Stimulate vigorous water sprout emergence
(D) Prevent all forms of fruit abscission

2012

68. The components of plant water potential (Ψ_w) are primarily defined by the equation:
(A) $\Psi_w = \Psi_s \times \Psi_p$
(B) $\Psi_w = \Psi_p - \Psi_s$
(C) $\Psi_w = \frac{\Psi_g}{\Psi_s}$
(D) $\Psi_w = \Psi_s + \Psi_p + \Psi_g$

side of the leaning stem
(C) Tension wood, formed on the upper side of the leaning stem
(D) Tension wood, formed on the lower side of the leaning stem

2010

49. The transition from active cambial growth to dormancy is primarily mediated by an increase in endogenous levels of:
(A) Gibberellins
(B) Indole-3-acetic acid
(C) Zeatin
(D) Abscisic acid

2004

50. Match the pruning concepts in List I with their physiological effects in List II.
List I: (Pruning Concept)
P. Summer pruning
Q. Winter pruning
R. Root pruning
S. Heading back
List II: (Physiological Effect)
1. Reduces vegetative vigor and alters C/N ratio in favor of fruiting
2. Stimulates vigorous new vegetative growth in spring
3. Temporarily restricts water and nutrient uptake to control size
4. Removes apical dominance and forces lateral bud break
(A) P-1, Q-2, R-3, S-4
(B) P-2, Q-1, R-4, S-3
(C) P-3, Q-4, R-1, S-2
(D) P-1, Q-3, R-2, S-4

2022

51. The physiological basis of pruning fruit trees often involves modifying the C/N ratio. A high Carbon to Nitrogen ratio generally promotes:
(A) Excessive levels of vegetative growth
(B) Reproductive growth and flower formation
(C) Rapid senescence of all existing leaves
(D) Suppression of the root system growth

2009

52. How does severe dormant pruning impact the sink-source relationship in the subsequent growing season?
(A) It decreases the root-to-shoot ratio, restricting water supply
(B) It forces carbohydrates to be sequestered permanently in the roots
(C) It completely halts the mobilization of stored metabolic reserves
(D) It increases the root-to-shoot ratio to drive vegetative growth

2016

53. Which pruning technique is least relevant for increasing canopy light penetration?
(A) Girdling
(B) Thinning out
(C) Central leader removal
(D) Canopy opening

2002

54. Carbohydrate partitioning in a heavily pruned tree is primarily directed towards:
(A) Rapid fruit maturation
(B) Embryo seed development
(C) Restoration of lost tissue
(D) Deep root system expansion

2014

55. The removal of mature leaves (defoliation) near a developing fruit cluster alters the sink-source dynamics by:
(A) Starving the fruit of locally synthesized photosynthates
(B) Enhancing sugar accumulation in the fruit due to reduced transpiration
(C) Forcing the fruit to become a primary source of carbohydrates
(D) Decreasing the physical weight of the shoot

2007

56. What is the effect of pruning on the hormonal balance within a woody shoot?
(A) Increases auxin levels, strictly inhibiting all lateral growth
(B) Causes an immediate and permanent depletion of gibberellins
(C) Elevates abscisic acid to induce immediate cellular dormancy
(D) Decreases auxin levels to permit cytokinin-driven bud break

2012

57. Identify the INCORRECT statement regarding the C/N ratio in pruning physiology.
(A) Heavy application of nitrogen fertilizers lowers the C/N ratio.
(B) A very low C/N ratio is the optimal trigger for intense fruit set.
(C) Reduced vegetative growth allows carbohydrates to accumulate, raising the C/N ratio.
(D) Pruning practices aim to balance the C/N ratio to sustain both yield and tree health.

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amounts of ethylene
(C) Auxin transport down the main stem is significantly reduced or inhibited
(D) The plant experiences severe phosphorus deficiency

2024

39. Which of the following represents the most appropriate architectural description of a highly determinate crop?
(A) Main axis growth arrests early after producing a terminal inflorescence
(B) It produces vegetative nodes endlessly along the main stem
(C) It lacks any branching and forms a single massive internode
(D) It exhibits strong sympodial growth exclusively in the roots

2010

40. Read the following assertion (A) and reason (R) and choose the correct option.
Assertion (A): Removal of the shoot apex typically results in the rapid growth of axillary buds.
Reason (R): The shoot apex acts as a strong sink for cytokinins and limits their availability to axillary buds, maintaining apical dominance.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2014

41. Environmental regulation of vascular cambium activity in temperate trees is most strongly influenced by:
(A) Influence of the monthly lunar cycle
(B) Photoperiod and temperature fluctuations
(C) Atmospheric nitrogen concentrations
(D) Average wind velocity over the canopy

2023

42. Hormonal regulation of secondary growth involves the synergistic action of:
(A) Auxin and ethylene
(B) Abscisic acid and jasmonic acid
(C) Auxin and cytokinin
(D) Salicylic acid and brassinosteroids

2017

43. Growth rings in tree trunks are formed primarily due to:
(A) The continuous death of phloem tissues throughout the calendar year
(B) Constant mechanical stress from high-velocity wind on the canopy
(C) Periodic alterations in root pressure levels during the night cycle
(D) Variations in xylem vessel size produced during different seasons

2008

44. Early wood (spring wood) differs from late wood (autumn wood) primarily in that early wood typically features:
(A) Wider vessels and thinner cell walls
(B) Narrower vessels and thicker cell walls
(C) Exclusive production of phloem sieve tubes
(D) Complete absence of lignin deposition

2025

45. The reactivation of vascular cambium in the spring is primarily triggered by a basipetal wave of which hormone from expanding buds?
(A) Cytokinin
(B) Auxin
(C) Ethylene
(D) Abscisic acid

2004

46. Identify the INCORRECT statement regarding the vascular cambium.
(A) It comprises fusiform initials and ray initials.
(B) Its activity is completely independent of environmental stress.
(C) It produces secondary xylem towards the inside and secondary phloem towards the outside.
(D) Drought conditions can lead to the formation of false growth rings.

2006

47. Which environmental factor induces dormancy in the vascular cambium of temperate perennial trees?
(A) Shortening photoperiod and chilling temperatures
(B) Increasing photoperiod and high temperatures
(C) High soil moisture and elevated atmospheric CO_2
(D) Increased availability of soil macronutrients

2012

48. Reaction wood formed in angiosperms to counteract leaning is called:
(A) Compression wood, formed on the lower side of the leaning stem
(B) Compression wood, formed on the upper

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2007

69. Osmotic adjustment is a physiological process defined as:
(A) Accumulating solutes to maintain cell turgor
(B) Physical shedding of leaves to prevent transpiration
(C) Rapid synthesis of aquaporins to block water uptake
(D) Conversion of xylem vessels to phloem tubes in drought

2014

70. Arrange the cellular components in the correct sequence representing the path of water during plasmolysis.
I. Vacuole
II. Cytoplasm
III. Plasma membrane
IV. External hypertonic solution
(A) I, II, III, IV
(B) IV, III, II, I
(C) II, I, III, IV
(D) I, III, II, IV

2009

71. In tree water relations, the pressure potential (Ψ_p) in healthy, fully turgid living cells is typically:
(A) Positive
(B) Highly negative
(C) Zero
(D) Equal to the matric potential

2007

72. Cellular plasmolysis occurs when a plant cell is placed in a:
(A) Hypotonic solution
(B) Isotonic solution
(C) Solution lacking nitrogen
(D) Hypertonic solution

2007

73. Which solute is most commonly accumulated in the vacuole during osmotic adjustment in drought-stressed trees?
(A) Lignin
(B) Proline
(C) Starch
(D) Cellulose

2017

74. Solute potential (Ψ_s) in a plant cell is always:
(A) Positive
(B) Equal to atmospheric pressure
(C) Negative or zero
(D) Fluctuating above zero

2003

75. What represents the primary consequence of extreme cellular plasmolysis in leaves?
(A) Rapid stomatal opening
(B) Enhanced photosynthetic rate
(C) Increased cellular division
(D) Loss of turgor and wilting

2019

76. Osmotic adjustment differs from simple dehydration mainly because osmotic adjustment involves:
(A) Active synthesis and transport of compatible osmolytes
(B) A passive concentration of solutes due to water loss
(C) The complete rupture of the plasma membrane
(D) Stomatal locking in the open position

2014

77. The ascent of sap in tall woody trees is best explained by which theory?
(A) Root pressure theory
(B) Cohesion-tension theory
(C) Capillarity theory
(D) Active transport theory

2007

78. Aquaporins facilitate water uptake primarily by:
(A) Actively pumping water against its concentration gradient
(B) Acting as selective and passive water channels in membranes
(C) Synthesizing ATP to drive bulk water movement in the plant
(D) Digesting the Casparian strip to allow free flow into xylem

2011

79. In radial transport across the root, the apoplastic pathway is blocked at the endodermis by the:
(A) Casparian strip
(B) Plasmodesmata
(C) Xylem parenchyma
(D) Pericycle

2024

80. Consider the following statements regarding water uptake:
I. The symplastic pathway involves water movement through plasmodesmata.
II. The apoplastic pathway occurs strictly through cell walls and intercellular spaces.
III. Aquaporins solely transport mineral nutrients.

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CHAPTER 10

Physiology of Horticultural and Plantation Crop Species

2015

1. Which of the following best defines the primary meristem in vascular plants?
(A) A tissue responsible exclusively for the lateral expansion of the stem and root
(B) A mature tissue layer that provides mechanical support to differentiating cells
(C) A secondary cambial layer that produces cork and phelloderm
(D) A group of undifferentiated cells at the apices of roots and shoots driving longitudinal growth

2014

2. Which growth phase is characterized by the highest rate of cellular expansion and vacuolization?
(A) Lag phase
(B) Logarithmic (exponential) phase
(C) Linear phase
(D) Senescence phase

2006

3. What is the primary role of the intercalary meristem in monocotyledons?
(A) Initiating the formation of secondary xylem
(B) Facilitating rapid stem elongation at the internodes
(C) Promoting the development of taproots
(D) Regulating the transition from vegetative to reproductive growth

2013

4. Identify the INCORRECT statement regarding plant growth differentiation.
(A) Dedifferentiation involves mature cells regaining meristematic activity
(B) Redifferentiation occurs when dedifferentiated cells mature into specific tissues
(C) Vascular cambium formation from parenchyma is an example of dedifferentiation
(D) Differentiation is strictly a reversible process in all plant tissues

2008

5. The transition from the exponential phase to the stationary phase in a standard sigmoidal growth curve is primarily caused by:
(A) Depletion of internal resources and spatial limitations
(B) Unrestricted availability of cellular nutrients
(C) Complete cessation of mitotic cell division globally
(D) Spontaneous genetic mutations preventing further expansion

2003

6. Which of the following pairs is correctly matched regarding cellular growth?
(A) Plasmolysis - Cellular expansion phase
(B) Lignification - Meristematic phase
(C) Mitosis - Cell division phase
(D) Vacuolization - Maturation phase

2024

7. The primary meristem originates directly from which of the following structures?
(A) Proembryo during embryogenesis
(B) Phellogen
(C) Interfascicular cambium
(D) Secondary xylem parenchyma

2015

8. In the context of cellular differentiation, what is the most significant consequence of secondary cell wall deposition?
(A) It initiates the process of cell division
(B) It increases the permeability of the cell membrane
(C) It promotes the formation of apical meristems
(D) It restricts further cellular expansion

2003

9. A researcher observes a plant tissue where cells have dense cytoplasm, prominent nuclei, and lack large vacuoles. This tissue is most likely in which phase of growth?
(A) Maturation
(B) Meristematic

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2001

92. Isohydric plants regulate their water status during drought by:
(A) Using stomatal control to maintain water potential
(B) Maintaining stomata open until complete desiccation
(C) Dropping all leaves immediately at the onset of drought
(D) Relying entirely on root pressure to survive the stress

2014

93. A tree species with very wide, long vessel elements is typically:
(A) Highly resistant to freezing-induced embolism
(B) Efficient at transport but vulnerable to cavitation
(C) Unable to transpire under high light conditions
(D) Devoid of any active stomatal regulation

2006

94. The mechanism of embolism repair in tall trees, in the absence of root pressure, is theorized to involve:
(A) Active transport of water by aquaporins into the air space
(B) Solute secretion into vessels driving osmotic water entry
(C) Mechanical compression of the stem by strong wind forces
(D) Complete regeneration of the xylem network overnight

2004

95. The primary physiological distinction between orthodox and recalcitrant seeds is that:
(A) Orthodox seeds tolerate desiccation; recalcitrant do not
(B) Orthodox seeds require light for germination to occur
(C) Orthodox seeds are found only in gymnosperm species
(D) Recalcitrant seeds undergo absolute dormancy for years

2012

96. Seed dormancy imposed by a hard, impermeable seed coat is termed:
(A) Physiological dormancy
(B) Morphological dormancy
(C) Physical dormancy
(D) Embryo dormancy

2014

97. Which phytohormone is primarily responsible for the induction and maintenance of seed dormancy?
(A) Gibberellic acid (GA)
(B) Cytokinin
(C) Ethylene
(D) Abscisic acid (ABA)

2007

98. The biochemical process of seed germination is generally considered to begin with:
(A) Radicle emergence
(B) Synthesis of chlorophyll
(C) Imbibition of water
(D) Depletion of endosperm reserves

2016

99. Stratification is an artificial horticultural technique mimicking natural conditions to break dormancy by exposing seeds to:
(A) High temperatures and dry conditions
(B) Moist, chilling temperatures
(C) Continuous intense light
(D) Concentrated sulfuric acid

2016

100. Consider the following statements concerning seed propagation:
I. Recalcitrant seeds lose viability quickly if dried below a critical moisture content.
II. Mango and Jackfruit produce orthodox seeds.
III. After-ripening is a period of dry storage that alleviates physiological dormancy.
IV. Gibberellins promote the mobilization of seed reserves during germination.
V. Scarification addresses physical dormancy.
Which of the above statements is/are correct?
(A) I, II, III and IV
(B) I, III, IV and V
(C) II, III, IV and V
(D) I, II, IV and V

2019

101. During the germination of cereal grains, the aleurone layer is stimulated to synthesize alpha-amylase by which hormone?
(A) Gibberellic acid
(B) Indole-3-acetic acid
(C) Abscisic acid
(D) Zeatin

2004

102. An agronomist notes that a batch of seeds fails to germinate even under optimal moisture and

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2016

168. Parthenocarpy in commercial edible bananas (Musa spp.) means the fruit develops:
(A) From the receptacle tissue rather than the ovary
(B) Only after manual cross-pollination
(C) Exclusively underground
(D) Without pollination or fertilization, remaining seedless

2018

169. Banana fruits are classified as climacteric. This indicates that during ripening, they exhibit:
(A) A steady, low rate of respiration
(B) A respiration peak with an ethylene surge
(C) Complete cessation of metabolic activity
(D) A requirement for exogenous auxins

2010

170. Consider the following statements about Banana and Papaya physiology:
I. Both are climacteric fruits.
II. Papaya is highly susceptible to waterlogging due to rapid root hypoxia.
III. 'Choke throat' in banana occurs when the inflorescence fails to emerge properly due to cold stress.
IV. Papaya fruit requires a significant drop in temperature to initiate ripening.
V. Banana bunches constitute a dominant sink drawing photosynthates from the pseudostem.
Which of the above statements is/are correct?
(A) I, II, III and V
(B) I, II, IV and V
(C) II, III, IV and V
(D) I, III, IV and V

2019

171. The physiological disorder 'choke throat' in banana is primarily induced by:
(A) Excessively high summer temperatures
(B) Severe nitrogen deficiency
(C) Pathogenic blockage of the xylem
(D) Cold stress impeding peduncle elongation

2016

172. Source-sink dynamics in a fruiting papaya tree are uniquely characterized by:
(A) Continuous production of leaves and fruits
(B) A strict seasonal separation of vegetative and reproductive phases
(C) The root system acting as the sole source of carbohydrates
(D) Fruits supplying sugars back to the expanding leaves

2017

173. What is the role of ethylene in the commercial ripening of bananas and papayas?
(A) It delays the degradation of chlorophyll
(B) It accelerates starch-to-sugar conversion
(C) It inhibits cell wall-degrading enzymes
(D) It prevents the accumulation of volatile aroma compounds

2011

174. Identify the INCORRECT pair regarding papaya physiology.
(A) Sex expression - Influenced by environmental factors like temperature
(B) Parthenocarpy - A universal, obligate requirement for all commercial papaya varieties
(C) Carpellody - Malformation of stamens into carpel-like structures due to low temperature
(D) Papain - Proteolytic enzyme abundant in unripe fruit latex

2016

175. Why is the retention of a sufficient number of functional leaves critical during the bunch development phase in banana?
(A) Leaves supply photosynthates to the sink
(B) To prevent sunburn on the pseudostem
(C) To synthesize ethylene needed for bunch emergence
(D) To maintain apical dominance over the suckers

2004

176. In grapes (Vitis vinifera), pruning-induced bud break is a standard viticultural practice primarily because:
(A) Grapes produce fruit strictly on old, lignified wood from previous seasons
(B) Unpruned vines never break dormancy
(C) Grapes fruit on new shoots from canes
(D) Pruning prevents the roots from taking up excess water

2001

177. The physiological disorder 'coulure' in grapes is defined as:
(A) The splitting of mature berries before harvest
(B) The uneven coloration of berries within a single cluster
(C) The failure of the vine to shed its leaves in winter
(D) Excessive drop of flowers or small berries

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(C) Cork cambium
(D) Vascular cambium

2017

114. The initial cellular event that occurs immediately following the mechanical wounding of grafting is:
(A) Differentiation of new xylem vessels
(B) Formation of mature phloem sieve tubes
(C) Proliferation of undifferentiated callus
(D) Immediate transport of starch at the cut

2023

115. Identify the INCORRECT statement regarding graft union formation.
(A) Callus formation is essential for a successful graft.
(B) Scion and rootstock cells fuse their nuclei to form hybrid cells at the union.
(C) Necrotic layers must be completely dissolved or broken by expanding callus.
(D) Vascular bridges are formed by the differentiation of callus cells into cambium.

2018

116. Graft incompatibility characterized by a clean break at the graft union and accumulation of starches above the union is typically classified as:
(A) Localized incompatibility
(B) Viral incompatibility
(C) Environmental incompatibility
(D) Translocated incompatibility

2013

117. Localized graft incompatibility is often overcome by:
(A) Using a mutually compatible interstock
(B) Defoliating the scion completely
(C) Applying gibberellic acid to the union
(D) Reversing the polarity of the scion

2017

118. A biochemical cause often implicated in localized graft incompatibility (e.g., Pear on Quince) is the production of:
(A) Excessive starch in the rootstock
(B) Overabundant chlorophyll at the site
(C) Breakdown of cyanogenic glycosides
(D) Neutral lipids blocking xylem vessels

2009

119. The formation of a continuous vascular bridge across the graft union is primarily directed by the flow of which substance from the scion?
(A) Auxin
(B) Water
(C) Abscisic acid
(D) Ethylene

2022

120. Match the stages of graft union formation in List I with their corresponding processes in List II.
List I: (Stage)
P. Stage 1
Q. Stage 2
R. Stage 3
S. Stage 4
List II: (Process)
1. Differentiation of new vascular cambium across the callus bridge
2. Intermingling and interlocking of callus cells
3. Formation of new secondary xylem and phloem
4. Formation of a necrotic layer and wound response
(A) P-4, Q-2, R-1, S-3
(B) P-1, Q-3, R-2, S-4
(C) P-2, Q-4, R-3, S-1
(D) P-4, Q-1, R-2, S-3

NODIA

2011

121. The phenomenon where a scion gradually overgrows the rootstock at the graft union is most likely an indicator of:
(A) Perfect graft compatibility
(B) Localized incompatibility or vigor mismatch
(C) Excessive water uptake by the roots
(D) Complete genetic uniformity

2024

122. Rootstock-scion interactions can significantly moderate the vegetative vigor of the scion. A dwarfing rootstock achieves this primarily by:
(A) Enhancing nitrogen transport to the scion
(B) Increasing the photosynthetic rate of leaves
(C) Reducing the flow of hormones and nutrients
(D) Causing constant cellular plasmolysis

2002

123. The physiological dwarfing effect of certain apple rootstocks (e.g., M9) is closely associated with:
(A) The complete absence of functional phloem
(B) Continuous production of gibberellins
(C) Their inability to anchor the tree
(D) A high ratio of bark to wood in roots

2008

124. How does a dwarfing rootstock generally impact the reproductive physiology of the scion?
(A) Induces precocity (early flowering and fruiting)
(B) Delays the onset of fruiting by several years
(C) Prevents the formation of floral buds entirely

2017

189. A major factor contributing to the incidence of granulation in sweet oranges and mandarins is:
(A) Severe drought stress during the vegetative phase
(B) Delayed harvest and large fruits on young trees
(C) Cultivation in highly saline soils
(D) Application of ethylene inhibitors

2005

190. Match the crop in List I with its specific physiological phenomenon in List II.
List I: (Crop)
P. Pineapple
Q. Citrus
R. Grape
S. Banana
List II: (Phenomenon)
1. Granulation
2. Veraison
3. Slip and sucker production
4. Choke throat
(A) P-3, Q-1, R-2, S-4
(B) P-1, Q-3, R-4, S-2
(C) P-3, Q-2, R-1, S-4
(D) P-2, Q-4, R-3, S-1

2016

191. To control physiological fruit drop in Citrus, foliar application of which hormone is commonly practiced?
(A) 2,4-D (at very low concentrations) or NAA
(B) Abscisic acid
(C) High concentration Ethylene
(D) Salicylic acid

2025

192. Which phenomenon allows pineapple to maximize water use efficiency?
(A) Opening stomata exclusively during the hot midday
(B) Lacking stomata completely on the upper leaf surface
(C) Stomatal opening at night to fix CO_2 into malic acid
(D) Shedding all leaves during a drought

2009

193. Identify the most accurate statement about pineapple reproduction.
(A) It requires cross-pollination by hummingbirds to set commercial fruit
(B) The fruit is a simple berry derived from a single ovary
(C) Flowering occurs uniformly without any external triggers
(D) Commercial varieties are self-incompatible and parthenocarpic

2015

194. Tea (Camellia sinensis) is ecologically adapted as an understory plant. Its ecophysiological shade response typically includes:
(A) Thicker leaves with increased specific leaf weight
(B) A transition from C3 to C4 photosynthesis
(C) Thinner, larger leaves with high chlorophyll
(D) Complete suppression of vegetative flushing

2003

195. Photosynthetically Active Radiation (PAR) optimal for maximum photosynthetic efficiency in tea without causing photoinhibition is:
(A) Full, direct equatorial sunlight
(B) Extremely low light (below compensation point)
(C) Partial shading (approx. 50-70% of full sunlight)
(D) Only wavelengths in the far-red spectrum

2013

196. The vegetative growth of tea is characterized by alternating periods of active shoot extension and rest. A resting bud is referred to as:
(A) A pekoe
(B) A flush
(C) A spur
(D) A banjhi bud

2002

197. The physiological objective of "plucking" in tea cultivation is to:
(A) Harvest tender shoots to stimulate flushing
(B) Remove all mature leaves to reduce transpiration
(C) Induce the plant into a deep state of winter dormancy
(D) Encourage the production of large, woody stems

2005

198. The biochemical quality of harvested tea shoots (e.g., catechin content) is strongly influenced by:
(A) The depth of the root system
(B) The amount of lignin in the main trunk
(C) Plucking intervals and maturity of the flush
(D) The color of the tea flower petals

2008

199. High atmospheric vapor pressure deficit (VPD) affects tea shoot dynamics primarily by:

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(C) Ethylene accumulation in the leaves
(D) Accumulation of florigen protein

2011

136. The concept of "competence" in floral physiology refers to:
(A) The competitive exclusion of lateral branches
(B) The speed of pollen tube elongation
(C) The plant's resistance to cold stress
(D) The ability of a bud to respond to floral inductive signals

2007

137. Identify the INCORRECT statement regarding floral differentiation in woody perennials.
(A) It represents the irreversible morphological commitment of the meristem.
(B) It occurs simultaneously with fruit ripening in all tree species.
(C) It is highly sensitive to environmental stresses like severe drought.
(D) Apical dome broadening is an early microscopic sign of differentiation.

2001

138. The transition from the vegetative to the reproductive phase at the meristematic level involves the upregulation of floral meristem identity genes, notably:
(A) FLOWERING LOCUS C (FLC)
(B) PHYTOCHROME B (PHYB)
(C) LEAFY (LFY) and APETALA1 (AP1)
(D) PIN-FORMED 1 (PIN1)

2021

139. Which environmental stress is known to occasionally force premature floral induction (stress-induced flowering) in certain woody species?
(A) Optimal nitrogen fertilization
(B) Heavy summer rainfall
(C) Elevated atmospheric oxygen
(D) Moderate drought

2011

140. Arrange the following events in the correct sequence for photoperiodic floral induction.
I. Expression of the CONSTANS (CO) gene
II. Perception of critical day length by phytochrome in leaves
III. Production of FT (Flowering Locus T) protein
IV. Transport of FT protein via phloem to the apical meristem
(A) II, I, III, IV
(B) I, II, IV, III
(C) II, III, I, IV
(D) III, I, II, IV

2023

141. The active form of phytochrome, which mediates photoperiodic responses, is:
(A) Pr (absorbs red light)
(B) Pfr (absorbs far-red light)
(C) Cryptochrome
(D) Phototropin

2007

142. Florigen, long theorized as the universal flowering hormone, has been identified molecularly as the:
(A) Gibberellic acid complex
(B) FT (Flowering Locus T) protein
(C) Ethylene gas
(D) Floricaula transcript

NODIA

2002

143. In Short-Day Plants (SDP), flowering is initiated when:
(A) The dark period exceeds a critical duration
(B) The day length strictly exceeds the critical photoperiod
(C) They are exposed to continuous light for 48 hours
(D) The night period is briefly interrupted by a flash

2011

144. Phytochrome conversion from Pfr back to Pr occurs naturally during:
(A) Exposure to intense sunlight
(B) The middle of a hot summer day
(C) Prolonged periods of darkness (dark reversion)
(D) Peak photosynthetic activity

2014

145. Which phenomenon confirms that leaves are the primary organs for photoperiod perception?
(A) Masking the shoot apex while exposing leaves induces flowering
(B) Defoliating the entire plant accelerates flowering
(C) Masking leaves and exposing only the shoot apex prevents flowering
(D) Both A and C

2016

146. A long-day plant (LDP) requires which of the following conditions for floral induction?
(A) A dark period longer than a critical maximum
(B) Exactly 12 hours of light and 12 hours of

temperature, yet the embryos are alive. The seeds are exhibiting:
(A) Quiescence
(B) Senescence
(C) Dormancy
(D) Recalcitrance

2015

103. The physiological advantage of seed dormancy in wild plant species is primarily:
(A) Preventing germination under lethal environments
(B) Ensuring all seeds germinate simultaneously
(C) Promoting immediate use of endosperm nutrients
(D) Eliminating the need for seed dispersal mechanisms

2019

104. Adventitious root formation on stem cuttings begins biologically with the process of:
(A) Cell senescence in the pericycle
(B) Lignification of the cambial layer
(C) Rapid abscission of existing leaves
(D) Cellular dedifferentiation of parenchyma

2004

105. The primary endogenous hormone facilitating root initiation in cuttings is:
(A) Gibberellin
(B) Auxin
(C) Cytokinin
(D) Ethylene

2022

106. In the practice of air layering, a strip of bark is removed (girdled). The physiological purpose of this is to:
(A) Stop water movement to the leaves
(B) Induce a wound response that solely produces ethylene
(C) Interrupt flow of carbohydrates and auxins at the cut
(D) Expose the xylem directly to soil moisture

2010

107. Which exogenous synthetic auxin is most widely used in commercial rooting powders for hard-to-root cuttings?
(A) Indole-3-acetic acid (IAA)
(B) 2,4-Dichlorophenoxyacetic acid (2,4-D)
(C) Naphthaleneacetic acid (NAA)
(D) Indole-3-butyric acid (IBA)

2016

108. Why is Indole-3-butyric acid (IBA) preferred over natural IAA for inducing rooting in cuttings?
(A) IBA is less susceptible to enzyme degradation
(B) IBA is transported strictly via the xylem
(C) IBA is highly unstable and degrades rapidly
(D) IBA prevents any cellular dedifferentiation

2015

109. Polarity in stem cuttings dictates that adventitious roots will naturally form at the:
(A) Morphological apex (distal end)
(B) Morphological base (proximal end)
(C) Center of the internode
(D) Tip of the emerging leaves

2007

110. Read the following assertion (A) and reason (R) and choose the correct option.
Assertion (A): Retention of a few leaves on a semi-hardwood cutting generally improves adventitious rooting.
Reason (R): Leaves are a continuous source of endogenous auxins and carbohydrates essential for root initiation.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2021

111. High concentrations of which hormone are known to generally inhibit adventitious root formation in cuttings?
(A) Cytokinin
(B) Auxin
(C) Salicylic acid
(D) Brassinosteroid

2015

112. The most critical anatomical requirement for the successful formation of an adventitious root primordium in a woody cutting is:
(A) The complete absence of epidermal cells
(B) A thick layer of suberin at the stem base
(C) Proximity of cells to the vascular cambium
(D) The disintegration of the primary xylem

2001

113. The success of a graft union fundamentally depends on the precise alignment of which tissue in the scion and rootstock?
(A) Epidermis
(B) Pith

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(C) Kills vegetative buds to allow flowers to emerge
(D) Occurs only in response to short days

2024

158. The phenomenon of alternate bearing (biennial bearing) in fruit trees like Mango is physiologically driven primarily by:
(A) Severe pruning practices during the "OFF" year
(B) Carbohydrate exhaustion and high gibberellins
(C) A genetic mutation occurring every alternate year
(D) Root pathogen attacks during heavy fruiting

2006

159. Spongy tissue in Mango is a critical physiological disorder primarily caused by:
(A) Soil heat and delayed ripening effects
(B) Excessive calcium in the soil
(C) Fungal infection of the fruit pulp
(D) Viral transmission via aphids

2005

160. Consider the following statements about Mango malformation:
I. It results in compact, sterile panicles that fail to set fruit.
II. It has both vegetative and floral forms.
III. High temperatures completely eliminate the disorder.
IV. Fusarium mangiferae and hormonal imbalances (ethylene/auxin) are heavily implicated.
Which of the above statements is/are correct?
(A) I, II and IV
(B) II, III and IV
(C) I, III and IV
(D) I and II

2015

161. A practical horticultural intervention to mitigate alternate bearing in Mango involves:
(A) Heavy nitrogen fertilization during the "ON" year harvest
(B) Completely defoliating the tree in winter
(C) Grafting onto a highly vigorous rootstock
(D) Restricting vegetative growth using paclobutrazol

2025

162. How does a heavy crop load in the current season negatively impact floral initiation for the following season?
(A) Fruits secrete high levels of abscisic acid that kills adjacent buds
(B) The physical weight of fruits breaks the vascular connections
(C) Sink dominance depriving buds of carbohydrates
(D) It causes an irreversible drop in root water potential

NODIA

2012

163. The physiological basis of the "ON" year in alternate bearing is characterized by:
(A) Abundant vegetative flushing and poor fruit set
(B) High induction and restricted vegetative growth
(C) Complete dormancy of all shoot apices
(D) Rapid shedding of all speculative leaves

2017

164. Which environmental factor exacerbates the occurrence of spongy tissue in susceptible mango cultivars like Alphonso?
(A) High soil moisture during ripening
(B) Continuous freezing temperatures
(C) Shading of the fruits
(D) High temperatures and poor ventilation

2003

165. Identify the INCORRECT statement regarding flowering physiology in mango.
(A) Flowering is independent of flush age
(B) Mango inflorescences are primarily terminal
(C) Both hermaphrodite and male flowers are present in the same panicle
(D) Low temperatures typically act as the inductive signal in subtropics

2009

166. Application of which chemical is often recommended to induce regular flowering in alternate bearing mango orchards?
(A) Gibberellic acid (GA_3)
(B) Silver thiosulfate
(C) Potassium nitrate (KNO_3)
(D) Colchicine

2016

167. In banana, the transition from vegetative growth to reproductive development (shooting) is marked internally by:
(A) The true stem transitioning to an inflorescence
(B) The emergence of a lateral branch from the rhizome
(C) The dropping of all leaves simultaneously
(D) The rapid lignification of the pseudostem

(D) Forces the tree into an alternate bearing cycle

2008

125. Nutrient transport across the graft union in a partially incompatible combination is often restricted, leading to scion leaves showing symptoms of:
(A) Nutrient toxicity
(B) Nutrient deficiency
(C) Gigantism
(D) Anthocyanin loss

2024

126. Rootstocks can impart tolerance to specific soil conditions. This is primarily a result of the rootstock's native:
(A) Above-ground canopy architecture
(B) Genetic exclusion mechanisms and robust roots
(C) Flower color and scent
(D) Fruit ripening traits

2021

127. Identify the most relevant concept regarding hormone transport across a graft union.
(A) Cytokinin produced in roots travels up to influence scion branching
(B) Hormones cannot cross the graft union under any circumstances
(C) Rootstocks completely degrade all scion-produced auxins
(D) Ethylene gas freely diffuses downward to control root architecture

2018

128. An alteration in scion fruit quality (e.g., sugar content or size) by the rootstock is fundamentally due to:
(A) Direct genetic transfer from rootstock to fruit seeds
(B) Physical contact of roots with the fruit
(C) Modification of nutrition and source-sink dynamics
(D) Rootstock photosynthesizing underground

2016

129. The use of interstocks in tree fruit propagation is primarily designed to:
(A) Increase the total height of the tree canopy
(B) Serve as the primary source of fruit production
(C) Replace the need for soil nutrients
(D) Overcome incompatibility or induce dwarfing

2021

130. Choose the correct sequence of hormone-driven events during rootstock-mediated dwarfing.
I. Decreased root volume
II. Reduced cytokinin synthesis and transport to scion
III. Shorter internodes and reduced shoot extension
IV. Lower scion vigor
(A) I, II, III, IV
(B) II, I, IV, III
(C) I, II, IV, III
(D) III, IV, II, I

2024

131. Floral induction is physiologically best described as:
(A) The physical emergence of petals from the bud
(B) Commitment of a meristem to form flowers
(C) The process of pollen tube growth
(D) The senescence of vegetative leaves

2009

132. Floral evocation occurs immediately after induction and involves:
(A) Visible swelling of the flower bud
(B) The abscission of unfertilized ovaries
(C) The transport of florigen from roots
(D) Apex changes preparing for differentiation

2022

133. Differentiation of floral parts in the meristem generally follows which centripetal sequence?
(A) Carpels, stamens, petals, sepals
(B) Sepals, petals, stamens, carpels
(C) Petals, sepals, carpels, stamens
(D) Stamens, carpels, sepals, petals

2012

134. In perennial woody species, floral initiation usually occurs:
(A) In the same season the fruit matures, just weeks before harvest
(B) During the winter dormancy period exclusively
(C) During the growing season preceding the year of anthesis (flowering)
(D) Instantly after seed germination

2021

135. Which endogenous factor acts as a strong antagonist to floral induction in many fruit trees, such as apple?
(A) Gibberellins from developing seeds
(B) High levels of carbohydrates in the spur

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2017

178. 'Millerandage' in grapes results in clusters containing both normal-sized and tiny, seedless berries. This is typically caused by:
(A) Excessive nitrogen application during ripening
(B) Sunburn of the cluster during mid-summer
(C) Poor fertilization during bad weather
(D) Over-pruning the canopy

2019

179. The period of rapid sugar accumulation and color development in grape berry physiology is termed:
(A) Anthesis
(B) Veraison
(C) Bud break
(D) Fruit set

2006

180. Read the following assertion (A) and reason (R) and choose the correct option.
Assertion (A): Application of hydrogen cyanamide (Dormex) is common in subtropical viticulture.
Reason (R): It breaks bud dormancy uniformly and compensates for the lack of adequate winter chilling.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2015

181. Grape berry development follows which characteristic growth curve pattern?
(A) Double sigmoidal
(B) Single sigmoidal
(C) Exponential
(D) Linear

2024

182. During the lag phase (Stage II) of grape berry development, which physiological process is most prominent?
(A) Rapid cell division and expansion
(B) Massive accumulation of hexose sugars
(C) Seed maturation and embryo development
(D) Breakdown of malic and tartaric acids

2011

183. Identify the INCORRECT statement regarding grape physiology.
(A) Tartaric acid concentration dramatically increases during the final stages of ripening
(B) Veraison marks the onset of ripening
(C) Gibberellic acid application is used to elongate clusters and thin berries in seedless varieties
(D) Water stress post-veraison can enhance fruit quality by concentrating sugars

2008

184. The phenomenon of "bleeding" in pruned grapevines in early spring is a physiological manifestation of:
(A) Transpiration pull
(B) Pathogenic decay of the wood
(C) Frost damage to the phloem
(D) Root pressure driving sap up the xylem

2019

185. In Pineapple (Ananas comosus), synchronous flowering is commercially achieved by the application of:
(A) High doses of nitrogen
(B) Ethylene releasing compounds (e.g., Ethephon)
(C) Gibberellic acid
(D) Abscisic acid

2018

186. Pineapple utilizes which specialized photosynthetic pathway, an adaptation to its native dry environments?
(A) C3 pathway
(B) C4 pathway
(C) Crassulacean Acid Metabolism (CAM)
(D) Photorespiration

NODIA

2005

187. The physiological fruit drop commonly observed in Citrus (e.g., "June drop") is naturally triggered by:
(A) Excessive accumulation of sugars in the fruit
(B) Complete lack of root pressure
(C) Over-pollination of the flowers
(D) Carbohydrate competition and water stress

2024

188. Granulation in Citrus fruits is a physiological disorder characterized by:
(A) Hard, dry, and gel-like juice vesicles
(B) The rind becoming excessively thin and prone to splitting
(C) The fruit dropping immediately after anthesis
(D) The accumulation of toxic heavy metals in the core

darkness
(C) A photoperiod exceeding a critical minimum length
(D) Strictly low temperatures combined with short days

2024

147. Identify the correct pair regarding photoperiodism.
(A) Day-neutral plants - Flowering is heavily dependent on specific day lengths
(B) Night break - Interruption inhibiting SDP flowering
(C) Obligate photoperiodic response - Flowering will eventually occur regardless of day length
(D) Photoreceptor - Auxin binding protein 1

2003

148. The primary conduit for the transport of the florigen signal from the leaf to the shoot apical meristem is the:
(A) Xylem vessels
(B) Apoplastic space
(C) Pith parenchyma
(D) Phloem sieve elements

2006

149. Thermoperiodism refers to the plant's response to:
(A) Diurnal fluctuations between day and night temperatures
(B) Constant extreme heat
(C) Extended periods of sub-zero freezing
(D) Soil temperature inversions

2003

150. Consider the following statements about chilling requirements:
I. Chill hours are generally calculated as hours accumulated between 0°C and 7.2°C.
II. Inadequate chilling leads to delayed and erratic foliation and flowering.
III. Rest breaking chemicals like hydrogen cyanamide can substitute for a lack of chilling.
Which of the above statements is/are correct?
(A) I and II
(B) I and III
(C) II and III
(D) I, II and III

2019

151. Vernalization is defined as the physiological process whereby flowering is promoted by:
(A) Promotion of flowering by cold exposure
(B) Short bursts of intense heat
(C) Increasing the daily photoperiod
(D) Applying high doses of nitrogen fertilizer

2025

152. The molecular basis of vernalization in model plants involves the epigenetic silencing of which repressor gene?
(A) CONSTANS (CO)
(B) LEAFY (LFY)
(C) APETALA1 (AP1)
(D) FLOWERING LOCUS C (FLC)

2003

153. Temperate fruit trees enter a state of deep physiological rest in winter known as:
(A) Quiescence
(B) Endo-dormancy
(C) Ecodormancy
(D) Paradormancy

2016

154. What happens to a temperate perennial tree (e.g., Apple) if grown in a tropical climate with no chilling hours?
(A) It grows continuously and produces abundant fruit year-round
(B) It dies immediately from heat stress
(C) It suffers from failure to flower and foliate
(D) It transitions completely to apomictic seed production

2025

155. Which phase of dormancy is purely enforced by unfavorable external environmental conditions (e.g., late spring frost)?
(A) Endodormancy
(B) Paradormancy
(C) Innate dormancy
(D) Ecodormancy

2023

156. The biochemical release from bud dormancy upon meeting chilling requirements is strongly associated with an increase in:
(A) Gibberellins and cytokinins
(B) Abscisic acid (ABA)
(C) Lignin precursors
(D) Starch synthesis

2023

157. Vernalization is distinct from breaking winter bud dormancy because vernalization specifically:
(A) Results in the immediate expansion of existing flower buds
(B) Confers the competence to initiate flowering at the meristem

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(A) Stomatal closure reducing shoot extension
(B) Accelerating the rate of shoot flushing
(C) Inducing massive adventitious root formation
(D) Promoting instant floral bud break

2023

200. Read the following assertion (A) and reason (R) and choose the correct option.
Assertion (A): Shade trees are commonly planted in tea plantations in hot, lowland regions.
Reason (R): They reduce leaf temperature, lower VPD, and prevent photoinhibition in the tea canopy.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2013

201. The transition of an actively growing tea shoot into a dormant "banjhi" state is often triggered by:
(A) Optimal soil moisture and high nitrogen
(B) Environmental stresses or hormonal feedback
(C) Application of gibberellic acid
(D) Heavy pruning of the framework

2017

202. Maintenance foliage in a tea bush is critical because:
(A) It provides the harvestable crop
(B) It synthesizes the toxins that repel all pests
(C) It is the photosynthetic source supporting new flushes
(D) It absorbs water directly from the atmosphere

2024

203. In Coffee (Coffea arabica / C. canephora), what specific environmental trigger is required to break floral bud dormancy (anthesis)?
(A) A significant drop in temperature to freezing
(B) Continuous 24-hour light exposure
(C) Exposure to short photoperiods
(D) Water stress followed by "blossom showers"

2014

204. If blossom showers are inadequate or heavily delayed, what is the most likely physiological consequence in coffee?
(A) Star flower formation and poor fruit set
(B) The floral buds revert to vegetative shoots
(C) Explosive and overly abundant flowering
(D) Immediate shedding of all foliage

2002

205. The biennial (alternate) bearing cycle in coffee is heavily driven by the competition for carbohydrates between:
(A) Developing root systems and new leaves
(B) Berries and next year's vegetative growth
(C) Old bark and new wood
(D) The main trunk and lateral branches

2007

206. During coffee bean development, the phase of rapid dry matter accumulation in the endosperm creates a massive demand for:
(A) Lignin
(B) Sucrose translocated from mature leaves
(C) Ethylene gas
(D) Anthocyanins

2011

207. Overbearing in coffee can lead to a severe physiological exhaustion known as:
(A) Dieback
(B) Coulure
(C) Spongy tissue
(D) Granulation

2007

208. Identify the correct statement regarding coffee physiology.
(A) Coffea arabica is primarily self-incompatible and requires cross-pollination.
(B) Flower buds differentiate entirely during the dry season just before the rains.
(C) Rapid berry expansion is sensitive to water stress
(D) Shade trees always reduce coffee yields regardless of the climate.

2005

209. To sustain high yields and minimize biennial bearing in coffee, the most critical physiological management strategy is:
(A) Allowing the bushes to grow completely unpruned
(B) Defoliating the plant entirely after harvest
(C) Preventing any blossom showers from reaching the soil
(D) Balancing nutrition for fruit and new node growth

2009

210. Match the physiological features in List I to the crop in List II.
List I: (Physiological Feature)
P. Banjhi bud formation
Q. Blossom showers for anthesis

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R. Veraison
S. CAM pathway
List II: (Crop)
1. Coffee
2. Tea
3. Pineapple
4. Grape
(A) P-2, Q-1, R-4, S-3
(B) P-1, Q-2, R-3, S-4
(C) P-2, Q-4, R-1, S-3
(D) P-3, Q-1, R-2, S-4

2010

211. In coffee, the period from flowering to bean maturity spans approximately:
(A) 2 to 3 weeks
(B) 2 to 3 months
(C) 7 to 9 months
(D) Over 2 years

2016

212. Canopy architecture in Coconut is structurally described as:
(A) A highly branched sympodial system
(B) A sprawling creeping vine
(C) A subterranean rhizome with no aerial stem
(D) A terminal meristem producing a crown of leaves

2003

213. The source-sink relationship in a mature coconut palm is continuous because:
(A) There is simultaneous growth of new leaves and spadices
(B) It produces only one massive fruit cluster every five years
(C) It stores all carbohydrates in the trunk and never utilizes them
(D) It lacks any significant sink organs

2001

214. Cardamom (Elettaria cardamomum) thrives optimally under which specific canopy light interception environment?
(A) Full, unshaded direct sunlight
(B) Filtered shade under a forest canopy
(C) Complete darkness
(D) Deep, heavily restricted light (below 10%)

2001

215. The reproductive physiology of coconut involves an inflorescence called a spadix. It typically exhibits:
(A) Protandry or protogyny based on variety
(B) Only female flowers
(C) Only male flowers
(D) Synchronized opening in tall varieties

2015

216. Cardamom produces its panicles (inflorescences) directly from:
(A) The apical bud of the tall aerial pseudostem
(B) The axils of leaves high up in the canopy
(C) The adventitious roots
(D) Rhizomes spreading along the soil surface

2002

217. Identify the primary physiological constraint to yield in closely planted, unthinned coconut plantations.
(A) Excessive root pressure causing trunk splitting
(B) Mutual shading reducing canopy photosynthesis
(C) Complete failure of the single apical meristem
(D) Overproduction of female flowers

2009

218. Successful fruit set in cardamom is highly dependent on:
(A) Wind pollination
(B) Parthenocarpic development
(C) Pollinator activity during morning hours
(D) Heavy mechanical shaking of the plant

2014

219. A coconut palm experiencing severe and prolonged drought will physiologically respond first by:
(A) Dropping its entire crown of leaves
(B) Converting its trunk into a water storage organ
(C) Developing a deep taproot instantly
(D) Aborting young nuts and new spathes

2004

220. Read the following assertion (A) and reason (R) and choose the correct option.
Assertion (A): Dwarf coconut varieties generally exhibit a higher degree of self-pollination compared to Tall varieties.
Reason (R): In Dwarf varieties, the male and female phases of the same inflorescence frequently overlap.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

NODIA

2001

221. Black Pepper (Piper nigrum) vines produce two distinct types of branches known as:
(A) Sympodial and Monopodial stems
(B) Orthotropic (climbing/vegetative) and Plagiotropic (fruiting/lateral) branches
(C) Tuberous and Rhizomatous stems
(D) Determinate and Indeterminate spurs

2005

222. Spike initiation in black pepper is highly sensitive to and usually triggered by:
(A) The onset of short days in winter
(B) Pre-monsoon showers after moisture stress
(C) Extended periods of sub-zero temperatures
(D) Extreme drought and high soil salinity

2010

223. Black pepper vines use adventitious roots at the nodes of orthotropic shoots primarily for:
(A) Clinging tightly to the supporting standard
(B) Absorbing most water and nutrients from soil
(C) Storing vast amounts of starch in the stem
(D) Synthesizing high levels of florigen protein

2008

224. Identify the INCORRECT statement regarding black pepper ecophysiology.
(A) It is a shade-loving plant that performs best under partial shade.
(B) It is highly sensitive to waterlogging, which severely limits root respiration.
(C) Spikes are produced exclusively on the rapidly climbing orthotropic shoots.
(D) Proper regulation of shade on the standard tree is critical for spike development.

2001

225. Berry development in black pepper from anthesis to harvest maturity typically takes about:
(A) 2 to 3 weeks
(B) 1 to 2 months
(C) 6 to 8 months
(D) 12 to 14 months

2023

226. What physiological role does the plagiotropic branch play in black pepper?
(A) It climbs the standard to extend vine height
(B) It forms underground storage organs
(C) It acts as the site for the emergence of reproductive spikes
(D) It actively repels all climbing insects

2006

227. Poor spike filling in black pepper is often physiologically linked to:
(A) Excessive exposure to sunlight and wind
(B) Micronutrient deficiency or low soil moisture
(C) Over-pollination by excessive bee activity
(D) Premature shedding of the clinging roots

2017

228. Which environmental condition is most detrimental to the active growth and survival of black pepper vines?
(A) Warm, humid tropical climate
(B) Well-distributed rainfall
(C) Gently sloping, well-drained terrain
(D) Prolonged waterlogging leading to root anoxia

2010

229. If a propagator wishes to establish a new black pepper garden that begins fruiting quickly, they should select cuttings exclusively from:
(A) Plagiotropic (lateral fruiting) branches
(B) The terminal climbing orthotropic shoots
(C) Underground runner shoots
(D) Seedling taproots

2009

230. Match the crop in List I to its characteristic growth pattern in List II.
List I: (Crop)
P. Mango
Q. Banana
R. Black Pepper
S. Coconut
List II: (Growth Pattern)
1. Pseudostem formed by overlapping leaf sheaths
2. Orthotropic and Plagiotropic branches
3. Single unbranched trunk with a terminal crown
4. Episodic rhythmic flushing
(A) P-4, Q-1, R-2, S-3
(B) P-1, Q-4, R-3, S-2
(C) P-4, Q-2, R-1, S-3
(D) P-3, Q-1, R-4, S-2

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in a single main axis. In sympodial growth, the terminal bud transforms into a flower, and growth is continued by lateral buds. Determinate growth ends in a terminal flower, while plagiotropic shoots grow horizontally rather than vertically upright.

38. (C) Auxin transport down the main stem is significantly reduced or inhibited
The physiological release of lateral buds from apical dominance occurs when the inhibitory influence of the shoot apex is removed or weakened. This usually happens when the downward transport of auxin from the terminal bud is significantly reduced. With lower auxin levels, the balance shifts in favor of cytokinins, which then stimulate the axillary buds to develop into new lateral branches.

39. (A) Main axis growth arrests early after producing a terminal inflorescence
A highly determinate crop is characterized by a growth pattern where the main axis stops elongating relatively early in the life cycle. This cessation of vegetative growth occurs because the apical meristem transforms into a terminal inflorescence. This architecture results in a more compact plant habit and often leads to a more synchronized period of flowering and fruit ripening.

40. (A) Both A and R are true and R is the correct explanation of A.
The removal of the shoot apex, known as decapitation, effectively eliminates the primary source of auxin, which normally maintains apical dominance. Furthermore, the apex acts as a strong metabolic sink for cytokinins. By removing this sink, cytokinins become more available to the axillary buds, promoting their rapid growth. Both the action and the explanation provided regarding hormonal redistribution are accurate.

41. (B) Photoperiod and temperature fluctuations
In temperate trees, the activity of the vascular cambium is highly sensitive to environmental signals that mark the changing seasons. Photoperiod, or day length, and temperature fluctuations are the primary drivers of this regulation. Longer days and warmer temperatures in spring stimulate cambial cell division, while shortening days and cooling temperatures in autumn signal the tissue to enter dormancy.

42. (C) Auxin and cytokinin
Secondary growth, which results in the thickening of stems and roots, is driven by the vascular cambium. This process is regulated by the synergistic interaction of auxin and cytokinin. Auxin, transported from the developing shoots, promotes the division of cambial initials, while cytokinin is essential for maintaining the meristematic identity and proliferation of these cells, ensuring continuous vascular tissue production.

43. (D) Variations in xylem vessel size produced during different seasons
Growth rings in the trunks of trees are the visible result of seasonal variations in the activity of the vascular cambium. These rings are formed due to differences in the size and wall thickness of xylem vessels produced throughout the year. The contrast between the large vessels of early wood and the small, thick-walled vessels of late wood creates boundaries.

NODIA

44. (A) Wider vessels and thinner cell walls
Early wood, also known as spring wood, is produced during the beginning of the growing season when water availability is high and growth is rapid. It typically features wider xylem vessels with thinner cell walls to facilitate efficient water transport. In contrast, late wood or autumn wood has narrower vessels and thicker walls, providing more mechanical support as the season concludes.

45. (B) Auxin
The reactivation of the vascular cambium in spring is initiated by a basipetal wave of auxin. As the buds begin to expand and grow, they synthesize large amounts of this hormone, which is then transported down the stem. This hormonal signal triggers the cambial cells to resume mitotic division after their winter dormancy, leading to the production of new secondary tissues.

46. (B) Its activity is completely independent of environmental stress.
The vascular cambium is a dynamic lateral meristem composed of fusiform and ray initials that produce secondary vascular tissues. However, it is incorrect to say its activity is completely independent of environmental stress. In fact, factors such as drought, extreme temperatures, and nutrient availability significantly influence cambial activity, sometimes even causing

thin primary cell walls. Additionally, these cells typically lack large central vacuoles and are actively involved in mitotic division, which provides the necessary increase in cell number required for the plant's development.

10. (A) I and II
Secondary meristems, such as the vascular cambium and cork cambium, are responsible for secondary growth, which increases the diameter or girth of the plant. These tissues develop from mature cells that have undergone dedifferentiation. While common in dicots and gymnosperms, they are typically absent in most monocot stems, which do not exhibit conventional secondary growth or wood formation.

11. (D) $\frac{W_2 - W_1}{t_2 - t_1}$
Crop Growth Rate represents the increase in plant dry weight per unit of land area per unit of time. It is a fundamental index used to assess the productivity of a crop community. The mathematical representation involves calculating the difference in total dry weight between two specific time intervals and dividing it by the duration of that time period.

12. (A) Ratio of total leaf area to the ground area
Leaf Area Index is a dimensionless quantity that measures the total upper leaf surface area of a crop canopy relative to the ground area it occupies. It is a critical indicator of a plant's ability to intercept light for photosynthesis. An optimal index ensures maximum light capture while minimizing excessive self-shading among the lower leaves in the canopy.

13. (B) Leaf area by leaf dry mass
Specific Leaf Area is a vital growth index that quantifies the leaf area produced per unit of leaf dry mass. It serves as an indicator of leaf thickness and density. Higher values suggest thinner leaves with a larger surface area for light interception per unit of biomass, which can influence the plant's overall photosynthetic strategy and resource allocation.

14. (B) Average photosynthetic efficiency of leaves
Net Assimilation Rate measures the increase in dry matter per unit of leaf area over a specific time period. It reflects the average photosynthetic efficiency of the leaves, accounting for losses due to respiration. This index is essential for understanding how effectively the plant's canopy converts light and carbon dioxide into biomass under varying environmental and developmental conditions.

15. (A) NAR and Leaf Area Ratio (LAR)
Relative Growth Rate represents the increase in plant biomass per unit of initial biomass over time. Conceptually, it is the product of Net Assimilation Rate, which reflects physiological efficiency, and Leaf Area Ratio, which reflects the morphological component of leafiness. Integrating these two indices provides a comprehensive view of how efficiently a plant is producing new dry matter.

16. (C) Increased mutual shading of leaves
As a plant community matures and the canopy becomes denser, the Net Assimilation Rate often declines. This reduction is primarily caused by the mutual shading of leaves, where the upper foliage intercepts most of the light. Lower leaves receive less radiation, falling near or below the light compensation point, which reduces the overall photosynthetic productivity of the plant system.

17. (D) SLA always increases steadily until the plant reaches complete senescence.
Growth indices like Specific Leaf Area fluctuate throughout the plant's life cycle based on environmental conditions and developmental stages. It does not always increase steadily until senescence; instead, it varies as leaf thickness and density change in response to light, nutrients, and age. Understanding these dynamics is essential for accurately modeling crop growth and predicting final yields.

18. (C) Photosynthetic rates of lower leaves are below the compensation point
When a crop reaches a very high Leaf Area Index, the upper leaves shade the lower ones so effectively that the lower foliage cannot perform efficient photosynthesis. These shaded leaves may reach the light compensation point, where respiration exceeds carbon fixation. Consequently, despite having a large total leaf area, the overall rate of biomass accumulation for the crop decreases.

19. (B) A large proportion of the biomass is allocated to leaves
A high Leaf Area Ratio indicates that a large proportion of the plant's total biomass is

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ANSWERS

1. (D) A group of undifferentiated cells at the apices of roots and shoots driving longitudinal growth
Primary meristems originate from the proembryo and are located at the tips of roots and shoots. They consist of undifferentiated cells that divide continuously, providing the basis for the primary plant body. This activity leads to longitudinal growth, or elongation, allowing the plant to increase in height and explore the environment for resources.

2. (C) Linear phase
The linear phase in the sigmoidal growth curve represents a period of constant and rapid growth following the exponential phase. It is fundamentally characterized by maximum cellular expansion and increased vacuolization within the cells. During this stage, the rate of increase in size remains high and steady before entering the stationary phase as resources become limited.

3. (B) Facilitating rapid stem elongation at the internodes
Intercalary meristems are unique tissues found at the base of nodes or leaf blades in monocotyledonous plants like grasses. Their primary physiological role is to facilitate rapid internode elongation, especially after the removal of the shoot apex by grazing or mowing. This specialized meristematic activity allows the plant to quickly regain height and biomass.

4. (D) Differentiation is strictly a reversible process in all plant tissues
Differentiation is the process by which meristematic cells undergo structural and functional changes to become specialized mature cells. While processes like dedifferentiation allow mature cells to regain meristematic activity, differentiation itself is generally considered a one-way developmental path in most biological contexts. Therefore, claiming it is strictly and universally reversible in all plant tissues is inaccurate.

5. (A) Depletion of internal resources and spatial limitations
The shift from the exponential growth phase to the stationary phase in plants is primarily driven by internal and external constraints. As the plant develops, internal nutrient resources may become depleted while physical space for further expansion becomes limited. These environmental and metabolic pressures eventually lead to a decline in the growth rate until a stable plateau is reached.

6. (C) Mitosis - Cell division phase
Cellular growth in plants involves distinct stages, beginning with the cell division phase where mitosis occurs to increase the total cell number. This is followed by cell expansion through vacuolization and finally maturation through differentiation and wall thickening. Mitosis is the biological process specifically responsible for nuclear and cytoplasmic division, providing the cellular building blocks for subsequent growth.

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7. (A) Proembryo during embryogenesis
The primary meristem is an embryonic tissue that originates directly from the proembryo during the early stages of embryogenesis. It remains active throughout the life of the plant, primarily at the apical regions of roots and shoots. This tissue is responsible for forming the primary plant body and initiating the first permanent tissues through continuous cell division.

8. (D) It restricts further cellular expansion
Secondary cell wall deposition is a critical event in cellular differentiation that provides structural rigidity and mechanical support. Once the secondary wall is laid down, often involving lignification, the cell becomes highly rigid and loses its ability to expand further. This process marks the transition from a growing cell to a mature, functionally specialized unit within the plant.

9. (B) Meristematic
Cells in the meristematic phase of growth are characterized by several distinct cytological features. They possess a dense cytoplasm, a relatively large and prominent nucleus, and

their presence is considered the least reliable or consistent indicator of maturity compared to actual flower production or distinct leaf shape changes throughout development.

29. (B) Photoperiodic signals and internal developmental competence
Floral induction during the phase change from juvenility to maturity requires the integration of external environmental cues with internal developmental readiness. The plant must first achieve competence, a state where it is capable of responding to photoperiodic or temperature signals. Once this internal threshold is met, the correct environmental conditions trigger the biochemical pathways necessary to transform vegetative meristems.

30. (A) III and V
While mature tissues struggle to form roots and rejuvenation can occur via micrografting, certain claims about juvenility are incorrect. Juvenility is rarely controlled by a single environmental trigger; it is a complex developmental process. Furthermore, the cone of juvenility refers to the lower, inner part of the tree, not the upper canopy, which is typically the most mature part.

31. (A) Auxin and Cytokinin
Apical dominance is the phenomenon where the main central stem of a plant grows more vigorously than the side stems. This process is primarily regulated by the opposing actions of auxin and cytokinin. Auxin, synthesized in the shoot apex and transported downward, inhibits the growth of axillary buds. Conversely, cytokinin, supplied from the roots, promotes bud break and lateral development.

32. (C) Vegetative growth continues without terminal flower formation
Indeterminate growth in a shoot is characterized by the continued activity of the apical meristem, which remains vegetative and does not transform into a terminal flower. This allows the shoot to produce nodes and internodes indefinitely throughout the growing season. In contrast, determinate growth occurs when the meristem eventually differentiates into a reproductive structure, effectively stopping further elongation of that axis.

33. (D) Alternating flushes of rapid extension and periods of rest
Many tropical woody perennials, such as mango, exhibit episodic or rhythmic growth patterns. Rather than growing continuously, these plants undergo alternating flushes of rapid shoot extension followed by periods of apparent rest. These cycles are regulated by internal hormonal signals and environmental cues, ensuring that growth occurs in synchronized bursts, which is a common architectural adaptation in evergreen trees.

34. (C) Short, condensed shoots that primarily bear flowers and fruits
Spurs are specialized, short, and highly condensed shoots found in many fruit trees, such as apple and pear. They are characterized by very short internodes and limited annual vegetative growth. Their primary physiological role is to serve as the main sites for the differentiation of floral buds and the subsequent bearing of flowers and fruits, making them essential for yield.

35. (B) Upright vegetative shoots emerging from older wood
Water sprouts are vigorous, upright vegetative shoots that emerge from latent buds on the older wood of a tree's trunk or main branches. They are often triggered by heavy pruning, limb breakage, or a sudden increase in light penetration. Because they grow rapidly and consume significant resources without producing fruit initially, they are typically removed or managed during pruning operations.

36. (A) Synchronized internal clocks regulating bud break
Rhythmic or episodic growth in tropical trees is largely governed by synchronized internal biological clocks that regulate the timing of bud break and dormancy. These endogenous rhythms allow the plant to coordinate its growth flushes independently of extreme seasonal temperature changes, which are absent in tropical environments. This mechanism ensures that vegetative expansion occurs in discrete intervals, optimizing resource utilization.

37. (A) Monopodial growth - Terminal bud remains active and dominant
Monopodial growth is a shoot architecture where the terminal apical bud remains active and dominant throughout the plant's life, resulting

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allocated to its leaves rather than to stems or roots. This ratio reflects the leafiness of the plant and its morphological investment in light-capturing surfaces. It is a key determinant of the initial growth rate, as more leaf area generally facilitates higher carbon assimilation.

20. (C) I, II and III
Relative Growth Rate quantifies the increase in material per unit of existing material per unit of time. Crop Growth Rate can be mathematically derived as the product of Leaf Area Index and Net Assimilation Rate. Additionally, Specific Leaf Area is the reciprocal of Specific Leaf Weight. However, Leaf Area Index measures surface area relative to ground, not the canopy volume.

21. (A) Is incapable of responding to floral induction stimuli
Juvenility in perennial plants is a physiological phase characterized by the inability to initiate flowers even when provided with ideal environmental induction. During this stage, the plant focuses on vegetative expansion and biomass accumulation. The transition to maturity, or phase change, marks the point where the plant gains the competence to respond to floral signals and enter reproduction.

22. (C) Lobed leaves and creeping growth habit
English Ivy exhibits distinct morphological differences between its juvenile and mature phases. The juvenile phase is characterized by a creeping growth habit, the production of adventitious roots along the stem, and distinctly lobed leaves. In contrast, the mature phase features erect stems, entire leaves without lobes, and the ability to produce flowers, illustrating dramatic physical changes during ontogenetic aging.

23. (A) A decline in rooting ability of stem cuttings
The transition from juvenility to maturity in woody perennials involves several physiological shifts. One of the most significant changes is a marked decline in the ability of stem cuttings to form adventitious roots. While juvenile tissues often root easily, mature tissues lose this regenerative capacity, making vegetative propagation more challenging for older trees unless specific rejuvenation techniques are applied.

24. (D) High levels of endogenous gibberellins present in the plant
The maintenance of the juvenile state in many woody plants is often associated with high endogenous levels of gibberellins. These hormones promote vegetative growth and can actively inhibit the transition to the reproductive phase. Experimental application of gibberellic acid can sometimes revert mature tissues to a juvenile-like state, suggesting that these hormones play a key role in regulating axologous aging.

25. (B) Lower parts of the tree trunk retain juvenile characteristics longer
Phase change in perennial trees does not occur simultaneously throughout the entire plant. Typically, the lower parts of the trunk and the innermost branches, which are chronologically older but ontogenetically younger, retain juvenile characteristics longer. This phenomenon creates a cone of juvenility at the base of the tree, while the peripheral and upper canopy branches transition to maturity first.

26. (C) Grafting juvenile seedling scions onto mature, flowering trees
Accelerating the transition from juvenility to maturity is a major goal in tree breeding. Grafting juvenile seedling scions onto mature, flowering trees is a common technique used to shorten the juvenile period. This process exposes the juvenile tissue to floral-inducing signals from the mature stock, facilitating a faster phase change and allowing researchers to evaluate fruit characteristics much earlier.

27. (D) Cuttings retaining the developmental phase of the source branch
Topophysis refers to the phenomenon where a vegetative propagule, such as a cutting or graft, retains the developmental phase or growth orientation of the specific branch from which it was taken. For example, a cutting taken from a mature, flowering branch may continue to grow in a mature state rather than reverting to the juvenile form characterized by its parent seedling.

28. (A) Presence of thorns
In citrus seedlings, the presence of thorns is often associated with the juvenile phase, while their reduction or absence can indicate maturity. However, because some mature cultivars naturally retain thorns while others do not,

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the formation of false rings when growth is interrupted.

47. (A) Shortening photoperiod and chilling temperatures
Cambial dormancy in temperate perennial trees is primarily induced by a combination of shortening photoperios and chilling temperatures in the autumn. These environmental cues trigger internal physiological changes, including a reduction in growth-promoting hormones and an increase in abscisic acid. This protective response allows the tree to stop secondary growth and prepare its tissues to survive harsh winter conditions.

48. (C) Tension wood, formed on the upper side of the leaning stem
When the stem or branch of an angiosperm tree leans, it produces specialized reaction wood called tension wood to correct its orientation. This wood forms on the upper side of the leaning structure. Tension wood contains specialized fibers with a high cellulose content that contract to pull the stem back toward a vertical position, ensuring the tree maintains its structural integrity.

49. (D) Abscisic acid
The transition from active secondary growth to dormancy in the vascular cambium is mediated by changes in the hormonal balance within the plant. A significant increase in endogenous levels of abscisic acid is a key signal for this process. This hormone acts as a growth inhibitor, helping to arrest cell division in the cambial layer and promoting protective winter buds.

50. (A) P-1, Q-2, R-3, S-4
Pruning techniques serve specific physiological purposes in fruit tree management. Summer pruning reduces vegetative vigor to favor fruiting, while winter pruning stimulates vigorous spring growth. Root pruning restricts resource uptake to control tree size. Finally, heading back involves the removal of the shoot apex, which eliminates apical dominance and forces the growth of lateral buds, resulting in a bushier canopy.

51. (B) Reproductive growth and flower formation
The Carbon to Nitrogen ratio is a physiological concept used to describe the balance between stored carbohydrates and available nitrogen. A high ratio, often achieved by reducing vegetative growth or limiting nitrogen, generally promotes reproductive development and the formation of flowers. This balance is crucial for fruit trees, as excessive nitrogen can lead to lush vegetative growth at the expense of yield.

52. (D) It increases the root-to-shoot ratio to drive vegetative growth
Severe dormant pruning removes a large portion of the shoot system while leaving the root system intact. This dramatically increases the root-to-shoot ratio, meaning more water and stored nutrients are available to each remaining bud. Consequently, the tree responds with extremely vigorous vegetative growth in the following season as it attempts to restore the balance between underground and above-ground biomass.

53. (A) Girdling
Increasing light penetration into the canopy is achieved through structural pruning techniques such as thinning out, removing the central leader, or general canopy opening. These methods physically remove branches to allow more sunlight to reach the interior. Girdling, however, is a technique that involves removing a strip of bark to interrupt carbohydrate flow; it is not primarily used for managing light.

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54. (C) Restoration of lost tissue
When a tree is heavily pruned, its internal resource allocation shifts significantly. The plant prioritizes the restoration of lost photosynthetic tissue to regain its metabolic capacity. Therefore, carbohydrate partitioning is primarily directed toward the rapid development of new vegetative shoots and leaves. This survival response often comes at the expense of other processes like immediate fruit maturation or deep root expansion.

55. (A) Starving the fruit of locally synthesized photosynthates
Removing mature leaves near a developing fruit cluster significantly alters the sink-source relationship. Since those nearby leaves are the primary source of locally synthesized sugars for the sink fruit, their removal starves the fruit of essential carbohydrates. This can lead to reduced fruit size, poor quality, or even premature abscission, as the fruit must then compete for limited resources.

56. (D) Decreases auxin levels to permit cytokinin-driven bud break
Pruning affects the hormonal balance by removing the shoot apices, which are the primary sites of auxin synthesis. The resulting decrease in auxin levels reduces apical dominance. This shift allows cytokinins, which are synthesized in the roots and transported upward, to become more effective at the remaining nodes. The higher cytokinin-to-auxin ratio then stimulates the break of lateral buds.

57. (B) A very low C/N ratio is the optimal trigger for intense fruit set.
The C/N ratio is a key physiological indicator where nitrogen promotes vegetative growth and carbon supports reproduction. While a higher ratio often favors flowering, it is incorrect to say that a very low C/N ratio is the optimal trigger for intense fruit set. In fact, a very low ratio usually results in excessive vegetative vigor and poor flowering, which is detrimental.

58. (C) Reduced tree size and improved fruit coloration
Summer pruning is performed during the active growing season and typically results in reduced overall tree size because it removes functional leaves and current-season growth. By altering carbohydrate partitioning and improving light penetration, this practice also tends to improve fruit coloration and quality. Unlike dormant pruning, it does not stimulate the same level of vigorous regrowth, making it effective for management.

59. (D) Gibberellin
The biochemical basis of dwarfing in many fruit trees is often linked to the reduced synthesis or transport of gibberellins. These hormones are essential for cell elongation and internode expansion. When gibberellin levels are low, either due to the genetic characteristics of a rootstock or the application of growth retardants, the plant develops shorter internodes and a more compact canopy.

60. (A) I, IV, III, II
In high-density planting systems, tree size reduction follows a logical sequence of competitive and physiological events. First, increased inter-plant competition for light and nutrients occurs. This is followed by mutual shading and a subsequent redistribution of hormones within the plant. These factors eventually alter the root system architecture and lead to a significant decrease in the individual canopy volume.

61. (B) Limiting nutrient uptake and hormonal signaling
Root restriction induces dwarfing by limiting the plant's capacity for nutrient and water uptake. Furthermore, the reduced root volume leads to a decrease in the synthesis and transport of root-derived growth signals, such as cytokinins and gibberellins. This limitation in both resources and hormonal signaling effectively suppresses shoot expansion and results in a smaller tree, which is beneficial for high-density planting.

62. (B) Maximizing light interception per unit area of land
High-density planting increases the physiological efficiency of an orchard by maximizing the interception of solar radiation per unit of land area. By planting trees closer together, the system ensures that a greater percentage of available light is captured by the canopy rather than hitting the ground. This intensive light capture drives higher total photosynthesis and productivity in a smaller space.

63. (A) Partial restriction of water and hormone flow
Dwarfing rootstocks control the vigor of the scion primarily through the partial restriction of water, mineral nutrients, and hormonal signals passing through the graft union. These rootstocks often have specific anatomical features, such as a higher proportion of bark, which increase hydraulic resistance. This reduced flow of essential resources and growth-promoting hormones directly limits the vegetative expansion of the scion.

64. (C) It shifts carbohydrate allocation to reproduction
Root restriction has a profound impact on the physiological development of a tree. By limiting vegetative vigor, it shifts the plant's carbohydrate allocation toward reproductive processes. This often results in precocity, where the tree begins to flower and bear fruit at an earlier age than unrestricted trees. This shift from vegetative to reproductive growth is a key benefit in orchard management.

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65. (D) Early cropping and higher initial yields
One of the most significant physiological and economic advantages of high-density planting is early cropping and higher initial yields. Because the trees are planted close together, the orchard reaches its full canopy potential and maximum light interception much sooner than a traditional wide-spaced orchard. This leads to a faster return on investment for the grower, although it requires intensive size management.

66. (C) Poor anchorage needing structural support
While dwarfing is beneficial for management and yield, severe dwarfing can lead to physiological disadvantages. One major issue is poor anchorage, as dwarfing rootstocks often have smaller, more brittle root systems that do not penetrate deeply into the soil. Consequently, these trees frequently require artificial structural support, such as trellises or stakes, to prevent them from leaning under heavy crop loads.

67. (B) Induce precocity and manage canopy size
The concept of root volume limitation is successfully applied in horticulture to manage canopy size and induce precocity. By restricting the space available for root growth, growers can effectively control the overall vigor of the tree. This technique forces the plant to transition into a reproductive state earlier, making it highly useful for container-grown plants, bonsai, and intensive fruit production systems.

68. (D) $\Psi_w = \Psi_s + \Psi_p + \Psi_g$
Plant water potential is a measure of the free energy of water in a system and determines the direction of water movement. It is defined as the sum of several component potentials, including solute potential, pressure potential, and gravity potential. Collectively, these factors describe the physical and chemical forces that influence how water is absorbed, transported, and utilized within tissues.

69. (A) Accumulating solutes to maintain cell turgor
Osmotic adjustment is a key physiological mechanism used by plants to tolerate drought and salinity stress. It involves the active accumulation of compatible solutes, such as proline or sugars, within the cell. This process lowers the cell's osmotic potential, which helps to maintain turgor pressure even as the external water potential decreases. This allows the plant to continue growing during stress.

70. (A) I, II, III, IV
During plasmolysis, water moves from an area of higher water potential inside the cell to a lower potential in the external environment. This process begins with water leaving the large central vacuole, followed by the cytoplasm. The water then crosses the plasma membrane into the external hypertonic solution. This sequential loss of water causes the protoplast to shrink away from the wall.

71. (A) Positive
In healthy, fully turgid living plant cells, the pressure potential is typically positive. This internal hydrostatic pressure, also known as turgor pressure, results from the influx of water into the cell, which pushes the plasma membrane against the cell wall. Turgor pressure is essential for providing mechanical support to non-woody tissues, facilitating cell expansion, and maintaining the structural integrity of leaves.

72. (D) Hypertonic solution
Cellular plasmolysis occurs when a plant cell is placed in a hypertonic solution, which has a higher solute concentration than the cell's interior. In this environment, the external water potential is lower than the internal potential, causing water to exit the cell via osmosis. As a result, the protoplast shrinks and the plasma membrane pulls away from the cell wall.

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73. (B) Proline
During osmotic adjustment, plants synthesize and accumulate specific compatible solutes in the vacuole and cytoplasm to lower their water potential. Proline, an amino acid, is one of the most common solutes accumulated in response to drought stress. Unlike starch or lignin, proline is highly soluble and does not interfere with cellular metabolism, making it ideal for maintaining turgor and membranes.

74. (C) Negative or zero
Solute potential, also known as osmotic potential, represents the effect of dissolved solutes on water potential. Because the presence of solutes always reduces the free energy of water, this value is always negative or zero in the case of pure water. As the concentration of solutes increases, the solute potential becomes increasingly negative, which is a fundamental driver for water movement.

results in shorter internodes and reduced shoot extension. Ultimately, these factors combine to lower the overall scion vigor, creating the characteristic compact growth habit.

131. (B) Commitment of a meristem to form flowers
Floral induction is the physiological process where a vegetative meristem is signaled to switch its developmental program to form flowers. This commitment occurs internally and is often invisible to the naked eye. Induction is triggered by various factors, including photoperiod, temperature, and internal hormonal status, and it precedes the actual morphological changes that result in the appearance of floral organs.

132. (D) Apex changes preparing for differentiation
Floral evocation is the stage that occurs immediately after induction, during which the apical meristem undergoes the necessary physiological and cellular changes to prepare for floral differentiation. This includes an increase in mitotic activity, changes in the shape of the apical dome, and the activation of specific genes. Evocation represents the bridge between the initial signal and visible differentiation.

133. (B) Sepals, petals, stamens, carpels
The differentiation of floral parts within the meristem typically follows a centripetal sequence, moving from the outside to the center. The process begins with the formation of the sepals, followed by the petals, then the stamens, and finally the carpels at the center of the flower. This highly coordinated developmental program ensures that the reproductive organs are correctly positioned for pollination.

134. (C) During the growing season preceding the year of anthesis (flowering)
In many perennial woody species, floral initiation usually occurs during the growing season preceding the year of anthesis. This means that the tree is already forming the next year's flower buds while the current season's fruits are still developing. This advanced preparation is critical for reproductive success, although it creates intense internal competition for resources between the fruit and the buds.

135. (A) Gibberellins from developing seeds
In many fruit trees, such as apple and mango, gibberellins produced by the developing seeds in the fruits act as strong antagonists to floral induction. These hormones are transported to nearby buds, where they inhibit the transition from vegetative to reproductive states. This inhibitory effect is a major cause of alternate bearing, where a heavy crop load prevents flowering for the next.

136. (D) The ability of a bud to respond to floral inductive signals
Competence in floral physiology refers to the ability of a specific bud or meristem to respond to floral inductive signals, such as photoperiod or chilling. A plant may be exposed to the correct environmental conditions, but if it has not yet achieved developmental competence, it will remain vegetative. This state is often linked to the transition from the juvenile to the mature phase.

137. (B) It occurs simultaneously with fruit ripening in all tree species.
Floral differentiation represents an irreversible morphological commitment of the meristem and involves distinct microscopic changes, such as the broadening of the apical dome. However, it is incorrect to state that it occurs simultaneously with fruit ripening in all tree species. The timing of differentiation varies widely among different fruit crops and is influenced by both genetic factors and varying environmental conditions.

138. (C) LEAFY (LFY) and APETALA1 (AP1)
The transition from the vegetative to the reproductive phase at the meristematic level is driven by the upregulation of floral meristem identity genes. Key examples include LEAFY and APETALA1, which direct the meristem to stop producing leaves and start forming floral organs. These genes act as master regulators, integrating various environmental and internal signals to ensure flowering occurs at the correct time.

139. (D) Moderate drought
Environmental stresses, such as moderate drought, are known to occasionally force premature floral induction in certain woody species. This phenomenon, often called stress-induced flowering, is thought to be a survival mechanism that allows the plant to reproduce before potential death. The stress triggers hormonal changes, such as increased abscisic acid, that favor the transition to the reproductive phase over growth.

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physical forces of evaporation and the properties of water. The system requires a continuous water column and operates under significant negative pressure within the xylem. Claiming that it depends on metabolic energy for movement is incorrect.

85. (A) Ion accumulation lowering osmotic potential
Root pressure is a physical phenomenon caused by the active accumulation of ions in the xylem of the roots. This process lowers the osmotic potential within the xylem, creating a gradient that draws water in from the surrounding soil. This influx of water generates a positive hydrostatic pressure that can push sap upward, often resulting in guttation during periods of low transpiration.

86. (C) Increased hydraulic resistance compared to the main stem
Hydraulic architecture in woody plants dictates that branch junctions possess increased hydraulic resistance compared to the main stem. This is often due to the narrowing of xylem vessels or changes in pit properties at the junction. This increased resistance acts as a safety mechanism, ensuring that the main trunk's water column remains stable even if a branch experiences significant tension or cavitation.

87. (A) Conduit diameter and pit properties
Xylem vulnerability to cavitation is highly correlated with the anatomical features of the water-conducting tissues, particularly the conduit diameter and pit membrane properties. Larger vessels are generally more efficient at transport but are more susceptible to the formation of air bubbles under high tension. The structure of the pit membranes determines how easily an air bubble can spread between vessels.

88. (D) Breaking the water column with a bubble
Embolism in xylem vessels primarily disrupts the ascent of sap by breaking the continuous water column with an air or vapor bubble. This blockage prevents the transmission of negative pressure from the leaves to the roots, effectively stopping the upward flow of water in the affected conduit. Large-scale embolism can lead to hydraulic failure, causing the plant to wilt and die.

89. (B) Closing to prevent excessive xylem tension
Stomatal regulation is a primary defense against hydraulic failure in trees. By closing their stomata during periods of high evaporative demand or soil water deficit, plants reduce the rate of transpiration. This prevents xylem tension from reaching critical levels that would trigger catastrophic cavitation and embolism. This trade-off between carbon gain and hydraulic safety is essential for survival in water-limited environments.

90. (A) I, II and IV
Cavitation involves the phase change of liquid water to vapor under high tension, and it can be induced by freeze-thaw cycles in temperate trees. Further, embolisms can sometimes be repaired through mechanisms like root pressure or local refilling. However, angiosperms, with their wide vessels, are often more vulnerable to cavitation than gymnosperms, whose smaller tracheids provide a more resistant hydraulic system.

91. (D) Pit membrane
The pit membrane is the structural feature that limits the spread of air bubbles between adjacent xylem vessels. These specialized portions of the cell wall act as a barrier, using surface tension to prevent air from an embolized vessel from entering a neighboring water-filled vessel. This compartmentalization ensures that hydraulic failure remains localized, allowing the plant to maintain water transport capacity.

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92. (A) Using stomatal control to maintain water potential
Isohydric plants regulate their water status during drought by using tight stomatal control to maintain a relatively constant leaf water potential. When soil moisture decreases or atmospheric demand increases, these plants close their stomata early to prevent excessive water loss. This conservative strategy helps avoid hydraulic damage but can lead to carbon starvation if the stomata remain closed for an extended period.

93. (B) Efficient at transport but vulnerable to cavitation
Tree species with very wide and long vessel elements are typically highly efficient at water transport, allowing for rapid growth and high transpiration rates. However, this efficiency comes at a cost, as these large conduits are much

75. (D) Loss of turgor and wilting
The primary consequence of extreme cellular plasmolysis in the leaves of a plant is the loss of turgor pressure, which leads to visible wilting. When cells can no longer maintain internal pressure against their walls, the entire tissue loses its structural rigidity. If the water deficit is not corrected, this process can lead to permanent damage, stomatal closure, and stopped photosynthesis.

76. (A) Active synthesis and transport of compatible osmolytes
Osmotic adjustment is a proactive physiological response that differs from simple dehydration. While dehydration involves a passive loss of water and concentration of existing solutes, osmotic adjustment involves the active synthesis and transport of compatible osmolytes. This metabolic investment allows the plant to maintain a favorable water potential gradient and sustain turgor, which is crucial for survival and continued growth.

77. (B) Cohesion-tension theory
The ascent of sap in tall woody trees is best explained by the cohesion-tension theory. This theory proposes that the evaporation of water from leaves creates a negative pressure, or tension, that pulls water upward from the roots. The process is made possible by the cohesive forces between water molecules and their adhesion to the xylem walls, forming a continuous column of water.

78. (B) Acting as selective and passive water channels in membranes
Aquaporins are specialized integral membrane proteins that act as selective and passive channels for the movement of water across biological membranes. They facilitate rapid water uptake by increasing the permeability of the cell membrane to water molecules. By regulating the abundance and activity of these channels, plants can finely tune their hydraulic conductivity in response to environmental changes.

79. (A) Casparian strip
In the radial transport of water across the root, the apoplastic pathway involves movement through the cell walls and intercellular spaces. However, this pathway is blocked at the endodermis by the Casparian strip, a band of suberin that is impermeable to water. This force-directs water and dissolved ions into the symplastic pathway, allowing the plant to selectively filter nutrient absorption.

80. (C) I and II
Water uptake in roots involves two main pathways: the symplastic pathway, which moves water through the living cytoplasm via plasmodesmata, and the apoplastic pathway, which occurs through the non-living cell walls. Both processes are essential for efficient transport. However, aquaporins are specialized channels primarily for water molecules, not for the direct transport of mineral nutrients, which requires specific ion carriers.

81. (D) Transpiration from the leaf surface
The driving force for the cohesion-tension mechanism is primarily generated by transpiration from the leaf surface. As water evaporates from the mesophyll cells into the atmosphere, it creates a negative pressure potential within the leaf xylem. This tension is transmitted through a continuous water column down to the roots, pulling more water into the plant to replace what was lost.

82. (C) Cohesive and adhesive forces
The continuous column of sap in xylem vessels is maintained by the cohesive and adhesive properties of water. Cohesion refers to the attraction between water molecules, which allows them to stay connected under tension. Adhesion is the attraction between water molecules and the cellulose in the xylem walls. Together, these forces prevent the water column from breaking even under negative pressure.

83. (B) Filter and selectively absorb ions
The transition of water from the apoplast to the symplast at the root endodermis is a critical regulatory step. By forcing water to pass through a living cell membrane, the plant can filter and selectively absorb ions while preventing the entry of harmful substances. This biological checkpoint ensures that the plant maintains a precise internal nutrient balance and controls xylem sap composition.

84. (D) It relies on active transport of water by xylem ATPases
The cohesion-tension mechanism is a passive process that does not rely on the active transport of water by ATPases. Instead, it is driven by the

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most favorable time for seedling establishment, whereas quiescence is simply a lack of water.

103. (A) Preventing germination under lethal environments
The primary physiological advantage of seed dormancy in wild plant species is to prevent germination under lethal or unfavorable environmental conditions. By delaying germination, dormancy ensures that the seedling emerges during a season that provides the best chances for survival and growth. This mechanism also spreads the risk of population failure over multiple years, which is a critical adaptation for survival.

104. (D) Cellular dedifferentiation of parenchyma
The biological process of adventitious root formation on stem cuttings begins with cellular dedifferentiation. During this phase, mature, specialized cells—typically parenchyma near the vascular cambium—revert to a meristematic state. These dedifferentiated cells then form a root primordium, which eventually develops into a functional adventitious root. This regenerative capacity is fundamental to the successful vegetative propagation of many woody species.

105. (B) Auxin
Auxin is the primary endogenous hormone that facilitates the initiation of adventitious roots in cuttings. It promotes the necessary cellular changes, including dedifferentiation and the formation of root primordia. While other hormones like cytokinin can inhibit rooting at high concentrations, auxin is essential for signaling the plant to divert resources and begin the developmental program required to regenerate a new root system.

106. (C) Interrupt flow of carbohydrates and auxins at the cut
In air layering, the removal of a strip of bark, known as girdling, serves a specific physiological purpose. This process interrupts the downward flow of carbohydrates and auxins through the phloem. These essential substances then accumulate at the upper edge of the cut, creating a localized high-concentration zone that stimulates the initiation of adventitious roots while the shoot remains attached.

107. (D) Indole-3-butyric acid (IBA)
Indole-3-butyric acid is the most widely used synthetic auxin in commercial rooting powders for hard-to-root cuttings. It is highly effective at stimulating root initiation across a broad range of species. Compared to other auxins, it provides a consistent response and is often combined with naphthaleneacetic acid to enhance its effectiveness, ensuring high success rates in vegetative propagation within nurseries.

108. (A) IBA is less susceptible to enzyme degradation
Indole-3-butyric acid is preferred over natural indole-3-acetic acid for inducing roots because it is significantly more stable and less susceptible to enzymatic degradation within the plant. This stability allows the hormone to remain active at the site of the cutting for a longer period, providing a sustained signal for root primordia development. Its reduced mobility also helps maintain high concentrations.

109. (B) Morphological base (proximal end)
Polarity in stem cuttings is an inherent physiological property that dictates the direction of hormone transport and tissue development. Regardless of the cutting's orientation, adventitious roots will naturally form at the morphological base, or proximal end, because auxin is transported basipetally. Understanding this polarity is crucial for ensuring that cuttings are placed correctly in the rooting medium to facilitate successful development.

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110. (A) Both A and R are true and R is the correct explanation of A.
Retaining a few leaves on semi-hardwood cuttings generally improves the success rate of adventitious rooting. This is because leaves act as a continuous source of endogenous auxins and carbohydrates, both of which are essential for the energy-intensive process of root initiation and growth. The provided reason correctly explains why the presence of leaves is beneficial for the physiological health of the cutting.

111. (A) Cytokinin
While auxin is essential for root initiation, high concentrations of cytokinin are known to generally inhibit the formation of adventitious roots in cuttings. Cytokinin promotes shoot development and cell division in a way that often antagonizes the specific cellular processes required to form a root primordium. Therefore, a

high auxin-to-cytokinin ratio is typically required to favor the regeneration of roots over shoots.

112. (C) Proximity of cells to the vascular cambium
The most critical anatomical requirement for the formation of adventitious root primordia in woody cuttings is the proximity of responsive cells to the vascular cambium. These cells, along with the phloem parenchyma and pericycle, possess the highest potential for dedifferentiation. Their location allows them to easily access the nutrients and hormones being transported through the vascular system to drive development.

113. (D) Vascular cambium
The success of a graft union depends fundamentally on the precise alignment of the vascular cambium in both the scion and the rootstock. The cambium is the only tissue capable of producing the new cells required to bridge the gap between the two partners. Proper alignment ensures that the resulting callus and subsequent vascular tissues can fuse into a continuous, functional connection.

114. (C) Proliferation of undifferentiated callus
Immediately following the mechanical wounding that occurs during grafting, the first cellular response is the proliferation of undifferentiated callus tissue. This callus originates from the cambial and parenchymatous cells at the cut surfaces of both the scion and rootstock. The formation of this mass of cells is essential for filling the air gaps and providing the foundation for subsequent vascular bridge development.

115. (B) Scion and rootstock cells fuse their nuclei to form hybrid cells at the union.
While callus formation and vascular bridge development are essential for a successful graft, the idea that scion and rootstock cells fuse their nuclei is incorrect. In a graft union, the two partners maintain their separate genetic identities; there is no nuclear fusion or formation of hybrid cells. Instead, the cells simply interlock and differentiate into a continuous vascular system for physiological communication.

116. (D) Translocated incompatibility
Translocated incompatibility is characterized by physiological symptoms that appear away from the graft union, such as the accumulation of starches in the scion and a clean break at the union. This type of incompatibility involves the movement of inhibitory substances or the failure of specific metabolites to cross the union. Unlike localized incompatibility, it cannot be overcome by using an interstock.

117. (A) Using a mutually compatible interstock
Localized incompatibility occurs when the scion and rootstock fail to form a functional connection due to direct adverse interactions at the union. This can often be overcome by using a mutually compatible interstock. The interstock acts as a physiological bridge, forming successful unions with both the scion and the rootstock, thereby bypassing the direct incompatibility and allowing for a stable, productive tree.

118. (C) Breakdown of cyanogenic glycosides
A biochemical cause of localized graft incompatibility, such as when pear is grafted onto quince, is the breakdown of cyanogenic glycosides. When the tissues of these incompatible partners meet, enzymes from one partner can release toxic cyanide from the glycosides of the other. This localized toxin production kills the cells at the union, preventing the formation of a functional connection and leading to failure.

119. (A) Auxin
The formation of a continuous vascular bridge across a graft union is primarily directed by the basipetal flow of auxin from the scion. This hormone signals the undifferentiated callus cells to differentiate into new cambial initials and subsequently into xylem and phloem. Without the steady supply of auxin from the growing buds of the scion, the vascular connection would fail to form properly.

120. (A) P-4, Q-2, R-1, S-3
Graft union formation occurs in several distinct stages. It begins with the formation of a necrotic layer as a wound response. This is followed by the intermingling and interlocking of proliferating callus cells. In the third stage, a new vascular cambium differentiates across the callus bridge. Finally, the production of new secondary xylem and phloem creates a continuous vascular system that supports growth.

121. (B) Localized incompatibility or vigor mismatch
The phenomenon where a scion gradually overgrows the rootstock at the graft union often indicates localized incompatibility or a significant mismatch in growth vigor between

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the two partners. This overgrowth reflects a disruption in the normal flow of carbohydrates and hormones, causing them to accumulate above the union. While not always leading to immediate failure, it can weaken the tree and reduce productivity.

122. (C) Reducing the flow of hormones and nutrients
A dwarfing rootstock moderates scion vigor primarily by reducing the flow of essential hormones, such as cytokinins, and mineral nutrients from the roots to the shoots. These rootstocks often have less efficient vascular systems or smaller root volumes, which limit the resources available for vegetative expansion. This physiological constraint forces the scion to grow more slowly, resulting in a smaller canopy.

123. (D) A high ratio of bark to wood in roots
The physiological dwarfing effect of certain apple rootstocks, like M9, is closely associated with their anatomical structure, particularly a high ratio of bark to wood in the roots. This structural characteristic is linked to reduced hormone and nutrient translocation. Furthermore, such rootstocks often have brittle roots and poor anchorage, which further limits their growth potential compared to more vigorous rootstock varieties.

124. (A) Induces precocity (early flowering and fruiting)
Dwarfing rootstocks generally have a positive impact on the reproductive physiology of the scion by inducing precocity. This means the tree begins to flower and produce fruit at a much earlier age than it would on a vigorous rootstock. By limiting vegetative growth, the rootstock ensures that more carbohydrates are available for floral initiation, which is desirable for modern high-density management.

125. (B) Nutrient deficiency
In partially incompatible graft combinations, nutrient transport across the union is often restricted due to a poorly developed or dysfunctional vascular connection. This disruption leads to the scion leaves showing symptoms of nutrient deficiency, even when the soil contains adequate levels of minerals. Common signs include chlorosis, reduced leaf size, and poor shoot growth, all reflecting the tree's inability to efficiently transport resources.

126. (B) Genetic exclusion mechanisms and robust roots
Rootstocks are frequently chosen for their ability to impart tolerance to specific adverse soil conditions, such as salinity or drought. This capability is a result of the rootstock's native genetic exclusion mechanisms and its robust root architecture. By utilizing a tolerant rootstock, a sensitive but high-quality scion variety can be successfully grown in environments where it would otherwise fail to thrive.

127. (A) Cytokinin produced in roots travels up to influence scion branching
The transport of hormones across the graft union is a critical aspect of scion-rootstock interaction. Cytokinins, which are synthesized in the root tips, travel upward through the xylem to influence scion branching and vigor. Conversely, auxins produced in the scion travel downward to regulate root growth. This continuous hormonal communication ensures that the two different genetic entities function as a single, coordinated plant.

128. (C) Modification of nutrition and source-sink dynamics
The alteration of scion fruit quality, such as sugar content or size, by the rootstock is fundamentally due to the modification of nutrition and source-sink dynamics. By controlling the uptake of water and minerals and influencing the distribution of carbohydrates, the rootstock indirectly affects the metabolic processes within the fruit. These physiological changes can significantly impact the commercial value of the harvest.

129. (D) Overcome incompatibility or induce dwarfing
Interstocks are used in tree fruit propagation primarily to overcome graft incompatibility between a desirable scion and a specific rootstock. Additionally, they can be employed to induce dwarfing or provide extra winter hardiness to the trunk. By inserting a compatible and functionally beneficial piece of stem between the scion and the rootstock, propagators can create a more stable and productive tree.

130. (A) I, II, III, IV
Rootstock-mediated dwarfing follows a clear physiological sequence. It begins with a decreased root volume or less efficient vascular system, which leads to reduced cytokinin synthesis and transport to the scion. This hormonal shift

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adaptation ensures that the plant's metabolic and developmental processes are synchronized with the natural daily temperature cycles found in its environment.

150. (D) I, II and III
Chill hours are essential for many temperate crops and are typically calculated as hours accumulated between 0°C and 7.2°C. Inadequate chilling leads to physiological issues, such as delayed and erratic foliation and flowering. To manage this in warmer climates, rest-breaking chemicals like hydrogen cyanamide are used to substitute for a lack of natural chilling, ensuring uniform and productive orchard performance.

151. (A) Promotion of flowering by cold exposure
Vernalization is a physiological process where the promotion of flowering is achieved through exposure to a period of cold. This requirement ensures that the plant does not flower prematurely during the autumn but instead waits until the winter has passed. Vernalization confers the competence to flower, although the actual appearance of flowers may require additional signals like a change in photoperiod.

152. (D) FLOWERING LOCUS C (FLC)
The molecular basis of vernalization involves the epigenetic silencing of the FLOWERING LOCUS C gene, which acts as a potent repressor of flowering. During a period of cold, the expression of this gene is gradually inhibited through histone modification. Once FLC is silenced, the plant is then able to express the genes necessary for floral induction when warmer temperatures occur.

153. (B) Endo-dormancy
Temperate fruit trees enter a state of deep physiological rest in winter known as endodormancy. This state is controlled by internal factors within the bud itself and cannot be broken by a simple return to favorable temperatures. The buds must first experience a specific amount of chilling to overcome this internal block. Only after the chilling requirement is met can the buds resume growth.

154. (C) It suffers from failure to flower and foliate
If a temperate perennial tree, such as an apple, is grown in a tropical climate without sufficient chilling hours, it will suffer from a failure to flower and foliate properly. The buds remain in a state of endodormancy because the chilling requirement is never met. This leads to erratic growth, poor leaf development, and a lack of fruit in conventional temperate orcharding.

155. (D) Ecodormancy
Ecodormancy is a phase of dormancy that is purely enforced by unfavorable external environmental conditions, such as freezing temperatures or lack of water. Unlike endodormancy, the buds are physiologically ready to grow but are prevented from doing so by the environment. As soon as the external conditions become favorable, the buds will immediately break and resume active growth, making this a flexible response.

156. (A) Gibberellins and cytokinins
The biochemical release from bud dormancy after meeting chilling requirements is associated with a dramatic shift in the plant's hormonal balance. There is a significant increase in growth-promoting hormones, specifically gibberellins and cytokinins, while the level of the inhibitor abscisic acid decreases. This change in the hormonal ratio signals the bud to reactivate its metabolic pathways, leading to cell division.

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157. (B) Confers the competence to initiate flowering at the meristem
Vernalization is distinct from the breaking of winter bud dormancy because it specifically confers the competence to initiate flowering at the meristem. While breaking dormancy allows existing buds to resume growth, vernalization is an inductive process that alters the plant's developmental state. Without vernalization, certain plants will continue to grow vegetatively even if their buds are active, as they lack the signal.

158. (B) Carbohydrate exhaustion and high gibberellins
Alternate bearing in mango is a physiological phenomenon driven by the depletion of carbohydrate reserves and high levels of gibberellins produced by developing seeds. A heavy crop load in the ON year consumes the available energy and inhibits floral induction for the following season. This results in an OFF year with little to no fruit, allowing the tree to recover its resources.

140. (A) II, I, III, IV
Photoperiodic floral induction follows a precise sequence of events. First, the perception of a critical day length occurs via phytochrome in the leaves. This leads to the expression of the CONSTANS gene, which in turn triggers the production of the FT protein, known as florigen. Finally, the FT protein is transported through the phloem to the apical meristem to initiate flowering.

141. (B) Pfr (absorbs far-red light)
Phytochrome is a photoreceptor that exists in two interconvertible forms: Pr and Pfr. The active form that mediates most photoperiodic and developmental responses is Pfr, which absorbs far-red light. Exposure to red light converts Pr into Pfr, triggering physiological changes such as floral induction in long-day plants. In darkness or under far-red light, Pfr is converted back to the inactive Pr form.

142. (B) FT (Flowering Locus T) protein
Florigen, the long-theorized universal flowering hormone, has been molecularly identified as the FT protein. This protein is synthesized in the leaves in response to inductive photoperiodic signals. Once produced, the FT protein travels through the phloem to the shoot apical meristem. At the apex, it interacts with other transcription factors to activate the genes responsible for the transition to floral growth.

143. (A) The dark period exceeds a critical duration
In Short-Day Plants, flowering is initiated only when the dark period exceeds a critical duration. These plants are more accurately described as long-night plants, as the length of the uninterrupted period of darkness is the actual deciding factor. If the dark period is interrupted by even a brief flash of light, the flowering response is inhibited, even if the day is short.

144. (C) Prolonged periods of darkness (dark reversion)
The conversion of phytochrome from its active Pfr form back to the inactive Pr form occurs naturally during prolonged periods of darkness. This process is known as dark reversion. Additionally, Pfr can be rapidly converted to Pr upon exposure to far-red light. The relative ratio of these two forms at any given time allows the plant to perceive the duration of light and dark.

145. (D) Both A and C
Experimental evidence confirms that leaves are the primary organs for perceiving photoperiodic signals. By masking the shoot apex while exposing the leaves to an inductive photoperiod, flowering can still be induced. Conversely, if the leaves are masked and only the shoot apex is exposed, flowering is prevented. This demonstrates that the signal for flowering is generated in the leaves and transported.

146. (C) A photoperiod exceeding a critical minimum length
Long-day plants require a photoperiod that exceeds a critical minimum length to initiate flowering. These plants typically flower in late spring or early summer as the days become longer. Physiologically, they are responding to the short duration of the night. If the dark period is shorter than a critical maximum, the plant will transition from vegetative growth to floral bud production.

147. (B) Night break - Interruption inhibiting SDP flowering
A night break is a brief interruption of the dark period with light, which can significantly alter the flowering response. In Short-Day Plants, a night break inhibits flowering because it prevents the accumulation of the required duration of continuous darkness. This phenomenon highlights the importance of the dark period as the primary regulator in the photoperiodic control of reproduction for many species.

148. (D) Phloem sieve elements
The primary conduit for the transport of the florigen signal, molecularly known as the FT protein, is the phloem sieve elements. After being synthesized in the leaf mesophyll cells in response to inductive signals, the protein is loaded into the phloem and travels along the sugar transport stream toward the shoot apical meristem. This long-distance signaling allows coordination of flowering.

149. (A) Diurnal fluctuations between day and night temperatures
Thermoperiodism refers to the physiological response of a plant to diurnal fluctuations between day and night temperatures. Many plants grow more vigorously or flower more effectively when subjected to a specific difference between the warm day and cool night. This

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more vulnerable to cavitation and embolism. This trade-off means such species are often restricted to environments with reliable water availability or possess sophisticated stomatal control.

94. (B) Solute secretion into vessels driving osmotic water entry
In the absence of root pressure, embolism repair in tall trees is theorized to involve the active secretion of solutes into the embolized xylem vessels. This process lowers the osmotic potential within the vessel, creating a gradient that drives the entry of water from surrounding living parenchyma cells. As water enters, it compresses the air bubble until it dissolves, restoring hydraulic continuity.

95. (A) Orthodox seeds tolerate desiccation; recalcitrant do not
The primary physiological distinction between orthodox and recalcitrant seeds lies in their tolerance to desiccation. Orthodox seeds can be dried to low moisture contents and stored at sub-zero temperatures without losing viability. In contrast, recalcitrant seeds are sensitive to water loss and die if dried below a critical threshold. This difference significantly impacts how these species are conserved and propagated in nurseries.

96. (C) Physical dormancy
Seed dormancy imposed by a hard, impermeable seed coat is specifically termed physical dormancy. This structural barrier prevents the entry of water or gases, which are necessary to initiate the germination process. In nature, this dormancy is broken by mechanical abrasion, fire, or microbial action. In horticulture, techniques such as scarification are used to bypass this barrier and ensure uniform germination.

97. (D) Abscisic acid (ABA)
Abscisic acid is the primary phytohormone responsible for the induction and maintenance of seed dormancy. It accumulates during seed maturation and prevents premature germination, even under favorable conditions. For germination to occur, the levels of abscisic acid must typically decrease, often in conjunction with an increase in gibberellins, which act as antagonists to promote the mobilization of reserves and embryo growth.

98. (C) Imbibition of water
The biochemical process of seed germination is generally considered to begin with the imbibition of water. This physical uptake of water triggers the reactivation of metabolic processes, including the hydration of proteins and the initiation of respiration. Imbibition is a prerequisite for all subsequent stages of germination, such as the synthesis of enzymes, the mobilization of stored reserves, and radicle emergence.

99. (B) Moist, chilling temperatures
Stratification is a horticultural technique that mimics the natural winter conditions required to break physiological seed dormancy. It involves exposing seeds to moist, chilling temperatures for a specific period. This treatment triggers internal biochemical changes, such as the reduction of germination inhibitors and the increase of growth promoters, ensuring that the seeds are ready to germinate when warmer temperatures arrive.

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100. (B) I, III, IV and V
Recalcitrant seeds lose viability if dried, while after-ripening is a period of dry storage that alleviates physiological dormancy. Gibberellins are essential for mobilizing seed reserves during germination, and scarification is specifically used to address physical dormancy caused by hard seed coats. However, mango and jackfruit do not produce orthodox seeds; they are recalcitrant, making that specific statement in the options incorrect.

101. (A) Gibberellic acid
During the germination of cereal grains, the embryo produces gibberellic acid, which diffuses to the aleurone layer. This hormone stimulates the aleurone cells to synthesize and secrete alpha-amylase, an enzyme that breaks down stored starch in the endosperm into simple sugars. These sugars provide the necessary energy and building blocks for the developing embryo until it becomes autotrophic through photosynthesis.

102. (C) Dormancy
When alive seeds fail to germinate even under optimal environmental conditions, they are exhibiting dormancy. This internal state prevents germination until specific physiological or physical requirements are met, such as chilling, light, or seed coat abrasion. Dormancy is a survival strategy that ensures seeds germinate at the

159. (A) Soil heat and delayed ripening effects
Spongy tissue is a critical physiological disorder in mango, particularly affecting cultivars like Alphonso. It is primarily caused by internal heat stress during fruit ripening, often exacerbated by high soil temperatures and poor ventilation within the canopy. This heat leads to the breakdown of pulp cells, resulting in a soft, yellowish, and unpalatable texture that significantly reduces the market value of the fruit.

160. (A) I, II and IV
Mango malformation is a complex disorder that results in compact, sterile panicles and abnormal vegetative growth. Both floral and vegetative forms exist, severely impacting productivity. The fungus Fusarium mangiferae and imbalances in hormones like ethylene and auxin are heavily implicated in its development. While management practices can reduce its incidence, it remains a major challenge in many mango-growing regions worldwide.

161. (D) Restricting vegetative growth using paclobutrazol
A common horticultural intervention to manage alternate bearing in mango involves the use of paclobutrazol. This chemical acts as a gibberellin inhibitor, which restricts excessive vegetative growth and promotes floral induction. By applying paclobutrazol during the OFF year, growers can encourage more regular and consistent flowering, helping to stabilize annual yields and improve orchard profitability.

162. (C) Sink dominance depriving buds of carbohydrates
A heavy crop load negatively impacts floral initiation for the next season primarily through sink dominance. The developing fruits act as powerful sinks that deprive nearby buds of the carbohydrates and nutrients required for the transition to a reproductive state. This resource exhaustion, combined with inhibitory signals from the fruit, prevents the tree from forming enough flower buds for the subsequent year.

163. (B) High induction and restricted vegetative growth
The ON year in the alternate bearing cycle is characterized by high floral induction and a heavy fruit set, which significantly restricts vegetative growth. During this phase, the tree's metabolic energy is almost entirely directed toward the development and maturation of the crop. This focus on reproduction prevents the formation of new vegetative flushes, which are necessary for producing flowers in the following season.

164. (D) High temperatures and poor ventilation
High temperatures and poor ventilation within the tree canopy are major environmental factors that exacerbate the incidence of spongy tissue in susceptible mango cultivars. These conditions prevent the dissipation of heat from the ripening fruit, leading to localized cellular breakdown. Cultivars like Alphonso are particularly sensitive to these stresses, making careful canopy management and timely harvesting essential to minimize this disorder.

165. (A) Flowering is independent of flush age
Mango flowering is a complex process where the inflorescences are primarily terminal and contain both male and hermaphrodite flowers. In the subtropics, low temperatures typically serve as the inductive signal. However, it is incorrect to say flowering is independent of flush age; in fact, only shoots of a certain maturity and age are typically capable of responding to floral signals and producing panicles.

166. (C) Potassium nitrate (KNO_3)
Foliar application of potassium nitrate is often recommended to induce regular and synchronized flowering in alternate-bearing mango orchards. This chemical is thought to stimulate the production of floral-inducing signals or alter the internal nutrient balance to favor reproduction. Using such treatments can help growers overcome the natural tendency for biennial bearing, leading to more predictable harvests and better orchard management.

167. (A) The true stem transitioning to an inflorescence
In the banana plant, the transition from vegetative to reproductive development is an internal process where the true stem, located at the base of the pseudostem, transforms into an inflorescence. This change is marked by the shoot apex switching from producing leaf primordia to forming floral parts. The resulting inflorescence then grows upward through the center of the pseudostem before finally emerging.

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During the day, the stomata remain closed to conserve water, while the stored acid releases CO_2 for photosynthesis.

187. (D) Carbohydrate competition and water stress
Physiological fruit drop in citrus, such as the June drop, is a natural mechanism used by the tree to adjust its crop load to its available resources. It is primarily triggered by competition for carbohydrates among the developing fruits and by periods of water stress. The tree abscises a portion of the young fruits to ensure that the remaining ones reach maturity.

188. (A) Hard, dry, and gel-like juice vesicles
Granulation is a physiological disorder in citrus where the juice vesicles become hard, dry, and gel-like. This occurs because the juice is replaced by polysaccharides and the vesicle walls thicken. The affected fruits feel lighter and have significantly reduced juice content and quality. This disorder primarily affects late-season fruit and is more common in certain cultivars and on vigorous trees.

189. (B) Delayed harvest and large fruits on young trees
A major factor contributing to the incidence of granulation in citrus is delayed harvesting and the production of large fruits, especially on young or overly vigorous trees. When fruit is left on the tree past its peak maturity, the physiological changes that lead to granulation are more likely to occur. Proper harvest timing and managing tree vigor are essential strategies for minimization.

190. (A) P-3, Q-1, R-2, S-4
Different horticultural crops exhibit unique physiological phenomena that are critical for their management. Pineapple is known for the production of slips and suckers, while Citrus is susceptible to the granulation of its juice vesicles. Grapes undergo veraison, marking the transition to ripening. In banana production, choke throat is a cold-induced disorder where the inflorescence fails to emerge properly during the growing season.

191. (A) 2,4-D (at very low concentrations) or NAA
To control physiological fruit drop in citrus, growers commonly use foliar applications of synthetic auxins like 2,4-D at very low concentrations or naphthaleneacetic acid. These hormones help to strengthen the abscission zone at the fruit stalk, preventing the premature separation of the fruit from the tree. This practice is particularly useful during periods of environmental stress when natural fruit drop is highest.

192. (C) Stomatal opening at night to fix CO_2 into malic acid
Pineapple maximizes its water use efficiency through its specialized CAM metabolism, where the stomata open at night to fix carbon dioxide. By absorbing CO_2 during the cooler, more humid night hours and keeping the stomata closed during the hot day, the plant significantly reduces its transpirational water loss. This adaptation allows pineapple to thrive in environments with low rainfall.

193. (D) Commercial varieties are self-incompatible and parthenocarpic
Commercial pineapple varieties are unique because they are self-incompatible and produce fruit parthenocarpically. This means the fruit develops without the need for pollination, ensuring it remains seedless and fleshy. In fact, pollination is actively avoided in commercial production, as it would lead to undesirable seeds. The resulting multiple fruit is formed from the fusion of many individual fruitlets on a single axis.

194. (C) Thinner, larger leaves with high chlorophyll
Tea is ecologically adapted as an understory plant, and its response to shade involves several ecophysiological changes. When grown under partial shade, tea typically produces thinner, larger leaves with a higher chlorophyll content. This strategy allows the plant to maximize light capture and maintain photosynthetic efficiency in lower light environments. These changes in leaf morphology also impact the biochemical quality profile.

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195. (C) Partial shading (approx. 50-70% of full sunlight)
The optimal photosynthetically active radiation for maximum photosynthetic efficiency in tea is partial shading, typically around 50% to 70% of full sunlight. Tea is sensitive to very high light intensities, which can cause photoinhibition and damage to the photosynthetic apparatus. By providing moderated light through shade trees,

triggered by environmental stresses, such as cold or rainy weather during bloom, or by internal nutrient imbalances. This failure of the flowers to transition into developing berries can lead to loose, poorly filled clusters and significantly reduced yields.

178. (C) Poor fertilization during bad weather
Millerandage in grapes results in clusters that contain a mixture of normal-sized berries and tiny, seedless ones, often referred to as chickens and hens. This condition is typically caused by poor fertilization or cold weather during the flowering period, which prevents some ovaries from developing seeds. While the tiny berries may be sweet, their presence makes the cluster look uneven.

179. (B) Veraison
Veraison is the specific period in grape berry development that marks the transition from growth to ripening. During this stage, the berries stop accumulating acid and begin to rapidly accumulate hexose sugars. In colored varieties, this phase is also characterized by the development of anthocyanins, leading to a visible change in berry color. Veraison is a critical milestone for determining harvest timing.

180. (A) Both A and R are true and R is the correct explanation of A.
In subtropical regions, the lack of sufficient winter chilling can lead to erratic and delayed bud break in grapevines. To overcome this, growers commonly apply hydrogen cyanamide, which acts as a chemical substitute for chilling. This treatment ensures that the buds break uniformly and at the desired time, which is essential for coordinating vineyard operations and achieving a synchronized harvest.

181. (A) Double sigmoidal
Grape berry development follows a characteristic double sigmoidal growth curve. This pattern consists of two periods of rapid growth separated by a lag phase. The first phase involves cell division and expansion, while the second growth phase, following veraison, is dominated by the accumulation of sugars and further volume increase. The intervening lag phase is the time when seeds mature.

182. (C) Seed maturation and embryo development
During the lag phase of grape berry development, which occurs between the two main growth periods, the actual expansion of the berry slows down significantly. Internally, this stage is most prominently associated with seed maturation and embryo development. While the fruit's volume remains relatively stable, these essential reproductive processes are completed, preparing the berry for the subsequent rapid ripening and sugar accumulation.

183. (A) Tartaric acid concentration dramatically increases during the final stages of ripening
Grape berry ripening involves veraison, the onset of sugar accumulation, and the use of gibberellic acid to manage cluster architecture. However, it is incorrect to state that tartaric acid concentration dramatically increases during the final stages of ripening. In fact, as the berry matures and accumulates sugars, the concentration of organic acids, including tartaric and malic acids, generally decreases due to dilution.

184. (D) Root pressure driving sap up the xylem
The phenomenon of bleeding in pruned grapevines in early spring is a visible manifestation of root pressure. As the soil warms and the roots become active, they pump water and minerals into the xylem. Since the leaves have not yet emerged to provide transpirational pull, the positive hydrostatic pressure forces the sap out of the pruning cuts, signaling vine reactivation.

185. (B) Ethylene releasing compounds (e.g., Ethephon)
In commercial pineapple production, synchronous flowering is achieved through the application of ethylene-releasing compounds such as ethephon. Naturally, pineapple flowering can be erratic and spread over a long period. By treating the plants with ethylene, growers can trigger simultaneous floral induction across the entire field. This allows for a more efficient harvest and better management of fruit size and market timing.

186. (C) Crassulacean Acid Metabolism (CAM)
Pineapple utilizes the Crassulacean Acid Metabolism pathway, which is a specialized photosynthetic adaptation to arid and seasonally dry environments. In this pathway, the plant opens its stomata at night to fix carbon dioxide into malic acid, which is stored in the vacuole.

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for carbohydrates between the current season's developing berries and the vegetative growth needed for next year's crop. A heavy fruit load can exhaust the tree's metabolic reserves, leaving insufficient energy for the production of new nodes and floral buds. This results in a poor harvest in the following year.

206. (B) Sucrose translocated from mature leaves
During the phase of rapid dry matter accumulation in the coffee endosperm, there is a massive demand for sucrose translocated from the mature leaves. This stage represents a significant sink for the plant's photosynthetic products. If the leaf area is insufficient or the supply of carbohydrates is restricted, the beans may not fill properly, leading to reduced yield and lower bean quality during harvest.

207. (A) Dieback
Overbearing in coffee, where the tree produces more fruit than its leaves can support, can lead to a severe physiological exhaustion known as dieback. This occurs as the developing berries drain all the available carbohydrates and nutrients from the rest of the plant. The lack of resources causes the death of shoots and roots, which can permanently damage or even kill the bush.

208. (C) Rapid berry expansion is sensitive to water stress
Coffee berry development is a complex process where the expansion of the fruit is highly sensitive to water stress. Any deficiency in water during this critical phase can lead to smaller beans and reduced overall quality. While Coffea arabica is primarily self-compatible and shade trees can be beneficial, the physiological sensitivity of fruit expansion to moisture availability remains a key factor in success.

209. (D) Balancing nutrition for fruit and new node growth
To sustain high yields and minimize the impact of biennial bearing in coffee, the most critical management strategy is balancing the nutrition for both fruit development and new node growth. By ensuring that the plant has enough resources to support the current crop while simultaneously producing the vegetative wood for the next year, growers can stabilize annual production through careful fertilization.

210. (A) P-2, Q-1, R-4, S-3
Different horticultural crops have distinct physiological features that define their management. Tea is characterized by the formation of banjhi buds, while coffee requires blossom showers to trigger anthesis. Grapes undergo veraison as a key ripening stage, and pineapple utilizes the specialized CAM photosynthetic pathway. Matching these features with the correct crop is essential for understanding their unique growth patterns and environmental requirements.

211. (C) 7 to 9 months
In coffee plants, the period from flowering to bean maturity typically spans approximately 7 to 9 months, depending on the variety and environmental conditions. During this long development time, the fruits undergo several stages, including rapid expansion and the filling of the endosperm with dry matter. This extended period makes the crop vulnerable to various environmental stresses, which can significantly impact bean quality.

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212. (D) A terminal meristem producing a crown of leaves
The canopy architecture of a coconut palm is structurally described as a single, unbranched terminal meristem that produces a crown of large leaves. This type of growth is characteristic of many palm species, where all new growth originates from a single central point at the top of the trunk. Because it lacks lateral branching, the health of this single meristem is absolutely critical.

213. (A) There is simultaneous growth of new leaves and spadices
The source-sink relationship in a mature coconut palm is continuous because the plant exhibits simultaneous growth of new leaves and reproductive spadices. Unlike seasonal crops, the coconut palm is constantly producing new sinks in the form of developing nuts at various stages. This requires a steady and uninterrupted supply of photosynthates from the existing canopy, making the maintenance of a crown essential.

214. (B) Filtered shade under a forest canopy
Cardamom is an ecologically sensitive plant that thrives optimally under the filtered shade of a forest canopy. It is adapted to the high humidity and moderated light levels found in

growers can maintain a high rate of carbon assimilation while protecting canopy health.

196. (D) A banjhi bud
In tea cultivation, the vegetative growth of the plant occurs in cycles of active flushing and rest. A resting bud that has temporarily stopped elongating is referred to as a banjhi bud. This state of temporary dormancy is a natural part of the plant's growth rhythm and can be influenced by environmental factors such as temperature and water availability. Management aims to minimize these.

197. (A) Harvest tender shoots to stimulate flushing
The primary physiological objective of plucking in tea cultivation is to harvest the tender young shoots, typically the terminal bud and the first two or three leaves. This process also serves to stimulate continuous flushing by removing apical dominance. By regularly harvesting these tips, the plant is encouraged to produce more lateral shoots, ensuring a steady supply of high-quality material throughout the season.

198. (C) Plucking intervals and maturity of the flush
The biochemical quality of harvested tea shoots, including their catechin and caffeine content, is strongly influenced by the plucking intervals and the maturity of the flush. Younger, more tender shoots generally contain a higher concentration of the compounds responsible for the flavor and health benefits of tea. Therefore, maintaining a precise plucking schedule is essential for ensuring a high-quality product.

199. (A) Stomatal closure reducing shoot extension
High atmospheric vapor pressure deficit significantly impacts tea shoot dynamics by increasing the rate of transpiration. To prevent excessive water loss, the plant responds by closing its stomata, which reduces the intake of carbon dioxide. This physiological response leads to a decrease in photosynthetic activity and slows down the rate of shoot extension and flushing, ultimately reducing the total yield during dry periods.

200. (A) Both A and R are true and R is the correct explanation of A.
In hot lowland regions, shade trees are a critical component of tea plantations. They serve a vital physiological function by reducing leaf temperature and lowering the vapor pressure deficit in the tea canopy. This helps to prevent photoinhibition and excessive transpiration, allowing the tea plants to maintain a more efficient metabolic state. The provided reason correctly explains these environmental benefits.

201. (B) Environmental stresses or hormonal feedback
The transition of an actively growing tea shoot into a dormant banjhi state is often triggered by environmental stresses or internal hormonal feedback. Factors such as a lack of soil moisture, extreme temperatures, or a buildup of certain growth inhibitors can cause the shoot apex to stop producing new leaves. This temporary cessation of growth allows the plant to conserve resources during unfavorable periods.

202. (C) It is the photosynthetic source supporting new flushes
Maintenance foliage refers to the mature leaves left on the tea bush below the plucking table. This foliage is critical because it acts as the primary photosynthetic source that supports the growth of new flushes and the overall health of the plant. While the young shoots are harvested, the maintenance leaves provide the energy and carbohydrates necessary for the regeneration of the crop.

203. (D) Water stress followed by "blossom showers"
In coffee plants, a specific environmental trigger is required to break floral bud dormancy and initiate anthesis. This process is typically triggered by a period of water stress followed by blossom showers or irrigation. The sudden availability of water after a dry spell signals the dormant buds to rapidly complete their development and open. This mechanism ensures that flowering occurs in a synchronized manner.

204. (A) Star flower formation and poor fruit set
If blossom showers are inadequate or heavily delayed, the coffee plant may experience a physiological disorder known as star flower formation. In this condition, the floral buds fail to open properly and instead develop into small, greenish, and sterile structures that do not set fruit. This failure of anthesis significantly reduces the potential yield, highlighting the importance of timely rainfall for successful reproduction.

NODIA

205. (B) Berries and next year's vegetative growth
The biennial or alternate bearing cycle in coffee is heavily driven by the intense competition

2009

10. Given below are two statements, one is labelled as Assertion (A) and the other is labelled as Reason (R):
Assertion (A): Ethylene receptors in plants, such as ETR1, act as negative regulators of the ethylene response pathway.
Reason (R): Binding of ethylene to its receptors activates the receptor's kinase activity, which directly turns on ethylene-responsive genes.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2009

11. During chloroplast dismantling, the key enzyme responsible for opening the porphyrin ring of pheophorbide a is:
(A) Pheophorbide a oxygenase (PAO)
(B) Chlorophyllase
(C) Mg-dechelatase (SGR)
(D) Red chlorophyll catabolite reductase (RCCR)

2002

12. Which of the following hormones is most universally recognized for accelerating petal senescence and abscission in cut flowers?
(A) Gibberellic acid
(B) Cytokinin
(C) Ethylene
(D) Indole-3-acetic acid

2025

13. The transcription factor families most strongly upregulated during the execution phase of leaf senescence belong to:
(A) MADS-box
(B) ARF and Aux/IAA
(C) PIN and LAX
(D) NAC and WRKY

2016

14. Senescence-Associated Gene 12 (SAG12) encodes which type of enzyme typically localized to senescence-associated vacuoles?
(A) Lipase
(B) Ribonuclease
(C) Cysteine protease
(D) Phospholipase D

2024

15. An apoptotic-like feature occasionally observed in plant Programmed Cell Death (PCD) is:
(A) Phagocytosis of dead cells by neighboring macrophages
(B) DNA laddering due to internucleosomal cleavage
(C) Rapid swelling and bursting of the plasma membrane
(D) Formation of a massive central vacuole

2021

16. The concept of physiological maturity in crop seeds is defined as the stage when:
(A) The seeds achieve the lowest possible moisture content under natural drying conditions
(B) The crop is visually ready for commercial harvest based on external color indicators
(C) Post-harvest lipid oxidation begins within the embryonic and endosperm tissues
(D) Maximum dry weight is reached and nutrient transport to the seed ceases

2015

17. Which post-harvest biochemical dynamic is primarily responsible for the toughening of asparagus spears during storage?
(A) Increased lignification and cell wall thickening
(B) Carbohydrate degradation into simple sugars
(C) Rapid protein breakdown into free amino acids
(D) Lipid peroxidation of the plasma membrane

2003

18. Accelerated aging tests assess seed viability loss by subjecting seeds to which specific environmental conditions?
(A) Extreme cold and vacuum storage
(B) High light intensity and low oxygen
(C) High temperature and high relative humidity
(D) Alternating wet and dry soil cycles

2017

19. A defining characteristic of climacteric fruits during ripening is:
(A) A sharp surge in respiration rate and autocatalytic ethylene production
(B) A steady decline in respiration without any significant ethylene synthesis
(C) The inability to ripen normally once detached from the parent plant body
(D) A complete dependence on abscisic acid for the accumulation of simple sugars

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the understory of tropical evergreen forests. Exposure to full, direct sunlight can cause leaf scorch and reduce growth, while too much shade can inhibit flowering. Finding the right balance is key.

215. (A) Protandry or protogyny based on variety
The inflorescence of the coconut palm, called a spadix, typically exhibits either protandry or protogyny, where the male and female flowers on the same spadix mature at different times. Protandry is common in tall varieties, promoting cross-pollination. This temporal separation of the sexes is a physiological mechanism that ensures genetic diversity. In some dwarf varieties, these phases may overlap, facilitating self-pollination.

216. (D) Rhizomes spreading along the soil surface
Cardamom is unique because it produces its panicles directly from the rhizomes that spread along the soil surface. These reproductive structures emerge from the base of the plant rather than from the aerial stems or leaf axils. Because the flowers and fruits are produced at ground level, they are highly dependent on soil moisture and the presence of soil-dwelling pollinators.

217. (B) Mutual shading reducing canopy photosynthesis
A primary physiological constraint to yield in closely planted coconut plantations is mutual shading, which significantly reduces canopy photosynthesis. When palms are too close together, their large leaves overlap, preventing light from reaching the lower portions of the crown. This leads to a decrease in the total amount of energy available for fruit development, resulting in fewer and smaller nuts produced.

218. (C) Pollinator activity during morning hours
Successful fruit set in cardamom is highly dependent on the activity of pollinators, particularly bees, during the morning hours when the flowers are most receptive. Cardamom flowers are not well-suited for wind pollination and require the physical transfer of pollen by insects to ensure fertilization. Therefore, maintaining a healthy population of pollinators near the plantation is essential for achieving high yields.

NODIA

219. (D) Abort young nuts and new spathes
A coconut palm experiencing severe and prolonged drought will first respond physiologically by aborting its young nuts and new spathes. This is a survival mechanism that reduces the plant's metabolic demand and conserves water and nutrients for the survival of the main terminal meristem. By shedding its energy-intensive sinks, the palm can maintain its structural integrity until moisture becomes available again.

220. (A) Both A and R are true and R is the correct explanation of A.
Dwarf coconut varieties are known to exhibit a higher degree of self-pollination compared to tall varieties. This is because the male and female reproductive phases within the same inflorescence frequently overlap, allowing pollen to reach the receptive flowers of the same plant. The provided reason correctly explains this physiological characteristic, which results in greater genetic uniformity and a more consistent fruit set.

221. (B) Orthotropic (climbing/vegetative) and Plagiotropic (fruiting/lateral) branches
Black pepper vines produce two distinct types of branches that serve different physiological functions. Orthotropic shoots are the main climbing stems that grow vertically and allow the vine to ascend its support. Plagiotropic branches are the lateral shoots that grow horizontally and are the primary site for the production of flowers and fruits. Understanding this distinction is essential for proper pruning and material selection.

222. (B) Pre-monsoon showers after moisture stress
Spike initiation in black pepper is a sensitive process that is usually triggered by the arrival of pre-monsoon showers following a period of moisture stress. This sudden increase in water availability after a dry spell provides the necessary physiological signal for the plant to transition into its reproductive phase. This timing ensures that developing berries have access to the abundant monsoon rainfall.

223. (A) Clinging tightly to the supporting standard
Black pepper vines possess specialized adventitious roots at the nodes of their orthotropic shoots, which they use primarily for clinging tightly to a supporting standard. These roots provide the necessary mechanical support

for the vine to climb and reach higher light levels. While they are not the main organs for water uptake, they are essential for the plant's climbing habit and stability.

224. (C) Spikes are produced exclusively on the rapidly climbing orthotropic shoots.
Black pepper is a shade-tolerant plant that thrives in humid tropical environments and is sensitive to waterlogging. It has distinct branch types, with the lateral plagiotropic branches being the primary sites for reproductive spikes. It is incorrect to say that spikes are produced exclusively on the climbing orthotropic shoots. These vertical shoots remain primarily vegetative, while the fruiting spikes are a plagiotropic feature.

225. (C) 6 to 8 months
The development of black pepper berries, from the time of anthesis to harvest maturity, typically takes about 6 to 8 months. During this period, the berries expand and accumulate the chemical compounds, such as piperine, that provide their characteristic flavor and pungency. The long duration of fruit development means that the plant requires consistent environmental conditions and adequate nutrition over several months.

226. (C) It acts as the site for the emergence of reproductive spikes
The plagiotropic branch plays a vital role in black pepper as the primary site for the emergence of reproductive spikes. Unlike the climbing orthotropic shoots, which focus on extending the vine's height, the horizontal plagiotropic branches are specialized for fruit production. These branches carry the flowers and subsequent berries, making them the most important part of the vine for determining final yield.

227. (B) Micronutrient deficiency or low soil moisture
Poor spike filling in black pepper is a physiological issue that is often linked to micronutrient deficiencies or low soil moisture during the critical phase of berry development. If the plant lacks the necessary resources to support all the developing berries on a spike, it may abort some or fail to fill them properly. Ensuring adequate nutrition and water management is essential for maximizing yield.

228. (D) Prolonged waterlogging leading to root anoxia
Prolonged waterlogging is the most detrimental environmental condition for the survival of black pepper vines. It leads to root anoxia, where the lack of oxygen prevents roots from respiring and functioning properly. This stress often triggers the development of soil-borne diseases such as foot rot, which can rapidly kill the vine. Therefore, planting black pepper on well-drained, sloping terrain is a critical practice.

229. (A) Plagiotropic (lateral fruiting) branches
If a propagator wants to establish a black pepper garden that begins fruiting quickly, they should select cuttings from the plagiotropic, or lateral fruiting, branches. Because these branches have already undergone the transition to a reproductive state, they will continue to produce spikes much sooner than cuttings taken from vegetative shoots. This selection allows growers to shorten the time to the first harvest.

230. (A) P-4, Q-1, R-2, S-3
Different horticultural crops exhibit characteristic growth patterns that define their structural and reproductive development. Mango is known for episodic rhythmic flushing, while the banana pseudostem is formed by overlapping leaf sheaths. Black pepper features a dual branch system with orthotropic and plagiotropic stems. Coconut is defined by a single, unbranched trunk topped with a terminal crown. Correctly identifying these patterns is fundamental.

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CHAPTER 11
Post-Harvest Physiology

2025

1. Which of the following best defines plant senescence in contrast to aging?
(A) A regulated, genetically programmed sequence of events leading to death
(B) A passive, unregulated deterioration of tissues due to age-related damage
(C) The localized cell death caused exclusively by external pathogenic attack
(D) The physical accumulation of damage without biochemical regulation or control

2014

2. Necrosis in plant tissues is distinct from programmed cell death (PCD) primarily because necrosis is:
(A) An energy-dependent process involving specific endonucleases and signal transduction
(B) Characterized by the orderly fragmentation of the nucleus into distinct bodies
(C) An unprogrammed cell death resulting from acute physical or chemical injury
(D) Dependent on the expression of Senescence-Associated Genes (SAGs) and proteins

2005

3. Progressive senescence in plants is most accurately observed when:
(A) Senescence progresses upward from the older basal leaves to the younger upper leaves
(B) All leaves and stems die simultaneously after the completion of the flowering cycle
(C) Only the uppermost leaves undergo rapid yellowing due to terminal nutrient depletion
(D) Leaves shed synchronously in response to decreasing autumn day lengths and temperatures

2021

4. Which pattern of senescence is typical of deciduous trees during autumn?
(A) Overall senescence
(B) Top senescence
(C) Progressive senescence
(D) Synchronous or deciduous senescence

2010

5. In monocarpic senescence, the massive remobilization of nutrients is primarily directed toward which sink?
(A) The developing root system
(B) The developing flowers and seeds
(C) The expanding apical meristem
(D) The mature basal leaves

2025

6. During monocarpic plant senescence, the breakdown of RuBisCO provides a major source of which remobilized nutrient?
(A) Potassium
(B) Phosphorus
(C) Nitrogen
(D) Calcium

2011

7. The conversion of S-adenosylmethionine (SAM) to 1-aminocyclopropane-1-carboxylic acid (ACC) in the Yang cycle is catalyzed by:
(A) ACC oxidase (ACO)
(B) Methionine synthase
(C) SAM synthetase
(D) ACC synthase (ACS)

NODIA

2010

8. Which intermediate compound is recycled back to methionine to sustain high rates of ethylene production in the Yang cycle?
(A) 5-Methylthioadenosine (MTA)
(B) S-adenosylhomocysteine (SAH)
(C) 1-aminocyclopropane-1-carboxylic acid (ACC)
(D) Malonyl-ACC (MACC)

2001

9. In the absence of ethylene, the primary role of the CTR1 protein in the ethylene signal transduction pathway is to:
(A) Positively regulate the transcription factor EIN3
(B) Actively suppress the downstream ethylene response pathway
(C) Act as a dominant negative receptor for ethylene
(D) Directly degrade ACC synthase

168. (D) Without pollination or fertilization, remaining seedless
Parthenocarpy in commercial edible bananas means that the fruit develops from the ovary without the need for pollination or fertilization. This process results in the seedless fruits familiar to consumers. While wild bananas produce hard seeds, the sterile, triploid nature of commercial varieties, combined with their parthenocarpic ability, ensures that the pulp remains fleshy and free of seeds for edible consumption.

169. (B) A respiration peak with an ethylene surge
Banana fruits are classified as climacteric, which means they exhibit a characteristic peak in respiration and a sudden surge in ethylene production during the ripening process. This hormonal signal triggers a cascade of biochemical changes, including the conversion of starch to sugar, the breakdown of chlorophyll, and the softening of the fruit tissues. This rapid ripening allows bananas to reach quality quickly.

170. (A) I, II, III and V
Both banana and papaya are climacteric fruits that exhibit a ripening surge. Papaya is notably sensitive to waterlogging, which causes rapid root hypoxia. In bananas, choke throat occurs when cold stress prevents the inflorescence from emerging properly. Additionally, the developing banana bunch acts as a dominant sink for photosynthates. However, papaya ripening is not strictly dependent on a large temperature drop.

171. (D) Cold stress impeding peduncle elongation
The physiological disorder choke throat in banana is primarily induced by cold stress during the time the inflorescence is emerging from the pseudostem. Low temperatures impede the elongation of the peduncle, causing the bunch to become trapped or emerge sideways through the leaf sheaths. This results in malformed bunches and significantly reduced yields, making temperature management critical for banana production in cooler regions.

172. (A) Continuous production of leaves and fruits
The source-sink dynamics in a fruiting papaya tree are unique because the plant produces leaves and fruits continuously throughout the year. This means that at any given time, the tree must balance the allocation of carbohydrates between expanding vegetative nodes and multiple stages of developing fruit. This constant competition requires a steady supply of nutrients and water to sustain both growth and productivity.

173. (B) It accelerates starch-to-sugar conversion
In the commercial ripening of bananas and papayas, ethylene plays a vital role by coordinating and accelerating the biochemical changes associated with fruit maturity. Specifically, it triggers the conversion of stored starch into simple sugars, which increases sweetness. It also activates enzymes that soften the cell walls and degrade chlorophyll, leading to characteristic changes in texture and color that indicate ripeness.

174. (B) Parthenocarpy - A universal, obligate requirement for all commercial papaya varieties
Papaya physiology involves complex sex expression influenced by temperature and the presence of the proteolytic enzyme papain in unripe fruit latex. Carpellody is indeed caused by low temperatures. However, parthenocarpy is not a universal requirement for all commercial papaya varieties; many cultivars require pollination to set fruit, making the claim that it is a universal, obligate requirement for all types incorrect.

175. (A) Leaves supply photosynthates to the sink
Retention of sufficient functional leaves is critical during the bunch development phase in banana because these leaves are the primary source of photosynthates for the developing fruit. The bunch acts as a massive metabolic sink, requiring a steady supply of sugars for expansion and sugar accumulation. Any reduction in leaf area due to disease or stress can lead to smaller bunches.

176. (C) Grapes fruit on new shoots from canes
Pruning is a standard practice in viticulture because grapes produce fruit on new shoots that emerge from canes or spurs. By pruning back the previous season's growth, growers can control the number and position of these new shoots, ensuring an optimal balance between vegetative vigor and fruit production. This practice also helps manage the canopy structure for better light penetration.

177. (D) Excessive drop of flowers or small berries
The physiological disorder coulure in grapes is defined as the excessive drop of flowers or very small berries shortly after anthesis. It is often

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2013

20. Given below are two lists. Match the items in List I with the mechanisms in List II.
List I: (Post-harvest Method)
P. 1-MCP (1-Methylcyclopropene)
Q. Controlled Atmosphere (CA) storage
R. AVG (Aminoethoxyvinylglycine)
S. Polyamine application
List II: (Primary Mechanism)
1. Inhibits ACC synthase activity
2. Delays senescence by maintaining membrane integrity
3. Competitively blocks the ethylene receptor
4. Reduces respiration by lowering oxygen and elevating carbon dioxide
(A) P-4, Q-3, R-1, S-2
(B) P-3, Q-1, R-4, S-2
(C) P-1, Q-4, R-2, S-3
(D) P-3, Q-4, R-1, S-2

2014

21. Which enzymatic change is most directly responsible for the softening of fruit cell walls during ripening?
(A) Accumulation of starch phosphorylase and other hydrolytic enzymes
(B) Increased activity of polygalacturonase and cellulase enzymes
(C) Inhibition of pectin methylesterase activity within the middle lamella
(D) Overexpression of lipoxygenase and other membrane-degrading proteins

2017

22. In the context of edible vaccines, the cholera toxin B (CTB) subunit is frequently targeted because it:
(A) Causes the primary virulence symptoms of cholera infection in human subjects
(B) Directly inhibits post-harvest senescence or deterioration in the host plant
(C) Acts as a mucosal adjuvant that binds to intestinal receptors
(D) Kills soil-borne plant pathogens during the active vegetative cultivation phase

2005

23. Which cellular organelle is the first to show visible ultrastructural signs of dismantling during leaf senescence?
(A) Nucleus
(B) Mitochondrion
(C) Golgi apparatus
(D) Chloroplast

2007

24. Which of the following pairings of senescence types and examples is INCORRECT?
(A) Progressive senescence - Agave and bamboo
(B) Overall senescence - Wheat and soybean
(C) Top senescence - Gladiolus and tulip
(D) Deciduous senescence - Maple and oak trees

2018

25. The process of nutrient remobilization during monocarpic senescence primarily occurs via which vascular tissue?
(A) Xylem
(B) Phloem
(C) Both xylem and phloem equally
(D) Apoplastic diffusion

2001

26. Which specific gaseous intermediate must be excluded from the CA storage environment to prevent accelerated ripening of apples?
(A) Nitrogen
(B) Ethylene
(C) Carbon dioxide
(D) Argon

2008

27. Identify the correct pair regarding ethylene receptors and their location.
(A) ERS1 - Endoplasmic reticulum membrane
(B) ETR1 - Plasma membrane
(C) EIN2 - Nucleus
(D) CTR1 - Chloroplast thylakoid

NODIA

2011

28. Which physiological disorder occurs in bananas when they are stored at temperatures below 13°C?
(A) Superficial scald
(B) Bitter pit
(C) Chilling injury
(D) Water core

2025

29. The structural change in chloroplasts during leaf senescence involves the formation of heavily lipid-loaded structures known as:
(A) Amyloplasts
(B) Prolamellar bodies
(C) Statoliths
(D) Plastoglobuli

2008

30. Given below are statements regarding flower senescence.
I. Ethylene-insensitive flowers such as gladiolus rely strictly on ethylene for wilting.

II. Tepal abscission without wilting is a common senescence pattern in some flowers.
III. Cytokinins generally delay the senescence of cut flowers.

Which of the above statement(s) is/are CORRECT?

(A) I and II
(B) I
(C) II and III
(D) III

2006

31. What is the fundamental difference between apoptosis in animal cells and programmed cell death (PCD) in plant cells?

(A) Plant cells do not require ATP for the execution of the death program
(B) Plant cells do not undergo phagocytosis due to their rigid cell walls
(C) Animal cells rely on vacuolar collapse and autolysis for cellular clearance
(D) Plant cells completely lack endonuclease activity during late-stage execution

2024

32. Harvestable (commercial) maturity in fruits is best described as the stage when:

(A) The fruit reaches maximum dry weight but remains in an inedible state
(B) The fruit has completed all internal biochemical synthesis and ripening pathways
(C) The fruit meets the requirements of the consumer or market processor
(D) Seeds inside the fruit are fully viable and exhibit deep primary dormancy

2013

33. The principal cause of vascular occlusion in cut flowers, leading to rapid wilting, is:

(A) Bacterial proliferation and formation of air embolisms in the xylem
(B) Excessive sugar accumulation in the xylem resulting from poor transport
(C) The collapse of phloem sieve tube elements and companion cell death
(D) Rapid lignification of the stem base immediately upon the cutting process

2014

34. Transgenic modification to improve tomato shelf-life (e.g., the Flavr Savr tomato) originally utilized which molecular technique?

(A) CRISPR-Cas9 knockout of ACC synthase
(B) Overexpression of the ETR1 mutant gene
(C) Antisense RNA technology targeting polygalacturonase
(D) RNA interference of lipoxygenase

2021

35. To significantly delay seed viability loss during long-term germplasm storage, it is most relevant to maintain:

(A) Low seed moisture content and sub-zero temperatures
(B) High seed moisture content to prevent desiccation injury
(C) High ambient oxygen concentrations
(D) Constant exposure to far-red light

2003

36. Which group of compounds provides a chemical barrier to gas exchange, mimicking modified atmosphere packaging when applied directly to fruits?

(A) Polyamines like spermine and spermidine applied via foliar spray
(B) Silver thiosulfate solutions used as ethylene perception inhibitors
(C) Jasmonic acid derivatives that regulate plant defensive responses
(D) Edible surface coatings like carnauba wax applied to the skin

2022

37. Which statement accurately identifies an advantage of using antisense RNA over traditional breeding for extending fruit shelf-life?

(A) Antisense RNA is a natural process that bypasses all biosafety regulatory scrutiny
(B) It allows for targeted downregulation of specific enzymes without altering other traits
(C) It enhances the ploidy level of the crop to create significantly larger fruits
(D) It improves the soil microbiome through the secretion of root-based transgenes

2019

38. The primary mechanism of seed nutritive degradation during prolonged storage under high relative humidity is:

(A) The spontaneous conversion of proteins to complex carbohydrates
(B) The physical shrinking of the seed coat
(C) Accelerated lipid peroxidation and enzymatic hydrolysis of stored reserves
(D) The accumulation of anthocyanins in the endosperm

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2017

39. Which of the following represents a non-climacteric fruit?
(A) Apple
(B) Banana
(C) Tomato
(D) Grape

2016

40. Select the correct sequence of events in the ethylene signaling pathway upon ethylene binding.
(A) Ethylene binds receptor → CTR1 is inactivated → EIN2 is cleaved → EIN3 promotes transcription
(B) EIN2 activation → CTR1 deactivation → EIN3 accumulation → Ethylene response
(C) Ethylene binds receptor → CTR1 is activated → EIN2 is degraded → EIN3 promotes transcription
(D) EIN3 accumulation → CTR1 activation → Ethylene binds receptor → EIN2 cleavage

2004

41. In the context of post-harvest physiology, modified atmosphere (MA) storage differs from controlled atmosphere (CA) storage because:
(A) MA actively utilizes vacuum pumps to remove all gases from the storage unit
(B) CA uses precise mechanical monitoring, while MA relies on film and respiration
(C) CA relies only on the fruit's respiration to passively alter the gas composition
(D) MA is used only for cut flowers, while CA is used exclusively for pome fruits

2015

42. Bitter pit in apples is a physiological disorder primarily associated with a localized deficiency of which mineral nutrient?
(A) Potassium
(B) Calcium
(C) Magnesium
(D) Boron

2010

43. Why is 1-MCP (1-Methylcyclopropene) highly effective at delaying fruit ripening?
(A) It irreversibly binds to the ethylene receptor, blocking subsequent signaling
(B) It chemically degrades endogenous ethylene into harmless gaseous byproducts
(C) It acts as a potent inhibitor of the ACC synthase and ACC oxidase enzymes
(D) It promotes the synthesis of abscisic acid, which directly antagonizes ethylene

2013

44. The most significant advantage of producing edible vaccines in transgenic plants is:
(A) The inability of plant viruses to mutate
(B) A tenfold increase in agricultural yield of the host crop
(C) Elimination of the need for cold chain logistics for vaccine distribution
(D) The bypass of the human mucosal immune system

2018

45. Which biochemical marker is most commonly measured to quantify the extent of lipid peroxidation during plant senescence?
(A) Sucrose
(B) Proline
(C) Glutathione
(D) Malondialdehyde (MDA)

2024

46. During the senescence of cut flowers, carbohydrate depletion specifically occurs because:
(A) Photosynthesis increases significantly while respiration stops entirely
(B) Starch is irreversibly converted into structural lignin in the petals
(C) Flower disconnection from sources combined with high respiration consumption
(D) The petals rapidly synthesize complex polysaccharides for cell wall support

2006

47. What role does silver thiosulfate (STS) play in floriculture post-harvest physiology?
(A) It provides essential heavy metals required for floral pigment accumulation
(B) It acts as a biocide and inhibits ethylene action at the receptor level
(C) It aggressively promotes the biosynthesis of ACC oxidase and related proteins
(D) It decreases the water potential of the storage solution to prevent cell lysis

2021

48. The "black layer" formation in the hilum region of corn kernels is a classic morphological indicator of:
(A) Harvestable maturity for sweet corn
(B) Fungal infection by Aspergillus
(C) Chilling injury
(D) Physiological maturity

2023

49. In plant programmed cell death (PCD) associated with senescence, the collapse of which organelle

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2003

86. Which phenomenon best describes the physiological basis of "superficial scald" in cold-stored apples?
(A) Complete degradation of the core parenchyma by the action of lipases
(B) Freezing of free water within the intercellular spaces of the fruit cortex
(C) Alpha-farnesene oxidation into conjugated trienes that kill epidermal cells
(D) Excessive accumulation of calcium and other divalent cations in the peel

2012

87. A major limitation of using edible vaccines derived from fruits (like tomatoes or bananas) compared to cereal seeds is:
(A) Fruits completely lack the ribosomes necessary for active protein synthesis
(B) Fruits cannot undergo genetic transformation using Agrobacterium vectors
(C) Fruits inherently destroy all foreign antigens during the ripening process
(D) High water content and short shelf life complicate storage and dosing

2012

88. A significant decrease in the ratio of which two hormones triggers the onset of leaf senescence?
(A) Cytokinin to Abscisic acid/Ethylene
(B) Auxin to Ethylene
(C) Gibberellin to Salicylic acid
(D) Jasmonic acid to Brassinosteroids

2022

89. Arrange the following events in chloroplast dismantling during senescence in the correct order:
I. Formation of primary fluorescent chlorophyll catabolites (pFCCs)
II. Cleavage of the porphyrin ring by Pheophorbide a oxygenase (PAO)
III. Removal of phytol chain by chlorophyllase
IV. Removal of magnesium by Mg-dechelatase (SGR)
(A) III, IV, II, I
(B) IV, III, II, I
(C) III, II, IV, I
(D) IV, II, III, I

2013

90. Arrange the following post-harvest handling steps for commercial cut flowers in the correct order:
I. Hydration in acidic water with biocides
II. Pre-cooling to remove field heat
III. Harvest at the optimal physiological stage
IV. Application of anti-ethylene treatments (e.g., STS or 1-MCP)
(A) III, I, II, IV
(B) III, II, I, IV
(C) III, IV, II, I
(D) III, II, IV, I

NODIA

2001

91. The gene SAG12 is strictly expressed only during age-dependent senescence. This makes its promoter highly useful in biotechnology for:
(A) Auto-regulating cytokinin production to delay senescence after development
(B) Driving the constitutive expression of insect resistance genes in all tissues
(C) Completely suppressing root development throughout the entire plant life cycle
(D) Inducing immediate cell death in expanding leaves through toxic protein synthesis

2019

92. Why do transgenic plants engineered with the SAG12-IPT construct exhibit a "stay-green" phenotype?
(A) The construct produces ethylene, which blocks chlorophyll breakdown in leaves
(B) The construct disables the PAO pathway irreversibly through gene silencing
(C) The construct synthesizes IPT at the onset of senescence to produce cytokinins
(D) The construct prevents the accumulation of abscisic acid during late maturity

2010

93. A primary factor causing chilling injury in cold-sensitive fruits (like bananas) at 4°C is:
(A) The spontaneous combustion of volatile esters within the fruit peel
(B) The immediate destruction of all cellular DNA by endogenous nucleases
(C) Hyperactivation of the Yang cycle leading to lethal ethylene levels
(D) A rapid phase transition of membrane lipids from fluid to a solid gel state

2018

94. Which class of post-harvest physical treatments is characterized by reducing O_2 levels to 1-3% and increasing CO_2 to 3-5%?
(A) Cold chain logistics
(B) Hypobaric storage
(C) Controlled Atmosphere (CA) storage
(D) Modified Atmosphere Packaging (MAP)

IgA upon encountering gut lymphoid tissue
(C) They trigger cell-mediated immunity without any subsequent antibody production
(D) Mucosal immunity from edible vaccines cannot protect against respiratory pathogens

2008

59. Which of the following is an intermediate in the conversion of chlorophyll a to primary fluorescent chlorophyll catabolites (pFCCs)?
(A) Red chlorophyll catabolite (RCC)
(B) Pheophytin b
(C) Protoporphyrin IX
(D) Heme

2008

60. Given below are two statements, one is labelled as Assertion (A) and the other is labelled as Reason (R):
Assertion (A): The application of polyamines to detached leaves or fruits can significantly delay senescence.
Reason (R): Polyamines structurally mimic ethylene and aggressively bind to the ETR1 receptor, triggering the ripening pathway.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2010

61. The Yang cycle requires a constant supply of which high-energy molecule to convert methionine to S-adenosylmethionine (SAM)?
(A) GTP
(B) NADH
(C) FADH2
(D) ATP

2009

62. Which post-harvest physiological condition results from storing tropical fruits like mangoes and papayas at 4°C?
(A) Accelerated autocatalytic ripening leading to rapid softening and decay
(B) Spontaneous starch retrogradation within the amyloplasts of the mesocarp
(C) Chilling injury including pitting, discoloration, and failure to ripen
(D) Water core development and the accumulation of sorbitol in the core tissue

2013

63. Which transcription factor, acting strictly downstream of EIN3, directly activates the transcription of secondary ethylene response genes like cellulase and polygalacturonase?
(A) MYB transcription factor
(B) ERF (Ethylene Response Factor)
(C) NAC transcription factor
(D) bZIP transcription factor

2023

64. A major biosafety concern associated with the cultivation of transgenic plants for edible vaccines is:
(A) The induction of severe autoimmune diseases within the host plant organism
(B) The rapid degradation of the vaccine protein by acids in the human stomach
(C) The mandatory need for extreme cold-chain logistics during post-harvest storage
(D) The potential for transgene flow to wild relatives or other food crops

2001

65. The term “climacteric” was originally used to describe:
(A) The abrupt rise in respiration accompanying the ripening of pome fruits
(B) The phase of maximum vegetative growth observed in commercial cereal crops
(C) The peak rate of photosynthesis occurring just before the leaf abscission event
(D) The sudden loss of seed viability occurring under conditions of high humidity

2011

66. A critical role of abscission zones in plant development is to:
(A) Facilitate the unchecked spread of necrotic lesions to the rest of the plant
(B) Increase the transpiration rate of senescing leaves during the drying phase
(C) Create a protective suberized scar tissue prior to the organ shedding event
(D) Connect the xylem of the parent plant tightly to the base of the shedding organ

2016

67. During programmed cell death in the formation of xylem tracheary elements, which process removes the protoplast?
(A) Autolysis mediated by the rupture of the central vacuole
(B) Extracellular phagocytosis by neighboring meristematic cells
(C) Rapid desiccation and hardening of the

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is considered the final execution step causing autolysis?
(A) The central vacuole
(B) The Golgi apparatus
(C) The rough endoplasmic reticulum
(D) The nucleolus

2022

50. Consider the following statements regarding the biochemistry of fruit ripening.
I. Starch is hydrolyzed into sugars, increasing sweetness.
II. Organic acid concentration generally increases, raising the titratable acidity.
III. Chlorophyll degradation is accompanied by the unmasking or synthesis of carotenoids/ anthocyanins.
IV. The production of volatile organic compounds decreases significantly to conserve energy.
Which of the above statements are INCORRECT?
(A) I and III
(B) I, II and IV
(C) II and IV
(D) I, III and IV

2023

51. The primary structural change that generates characteristic fruit aromas during ripening is the synthesis of:
(A) Esters, alcohols, and aldehydes from fatty acids and amino acids
(B) Complex hemicelluloses and branched xyloglucans in the cell wall
(C) Polygalacturonic acid sequences that determine tissue firmness
(D) Insoluble tannins and phénolics that contribute to fruit astringency

2007

52. RNA interference (RNAi) is used in molecular approaches to shelf-life improvement to:
(A) Induce mutations randomly across the entire plant genome using chemical agents
(B) Synthesize novel proteins that physically coat the fruit to prevent water loss
(C) Overexpress genes responsible for endogenous polyamine synthesis and transport
(D) Degrade specific mRNA transcripts to silence the expression of ripening genes

2013

53. Which hormone typically functions antagonistically to ethylene in regulating leaf senescence?
(A) Abscisic acid
(B) Cytokinin
(C) Salicylic acid
(D) Jasmonic acid

2002

54. The degradation of proteins during post-harvest storage of field crops is predominantly catalyzed by:
(A) Lipoxygenases
(B) Amylases
(C) Proteases and peptidases
(D) Pectinases

NODIA

2023

55. What is the fundamental mechanism behind a non-climacteric fruit's biochemical difference from a climacteric fruit during the ripening phase?
(A) Non-climacteric fruits exhibit a massive surge in ACC synthase activity.
(B) Non-climacteric fruits do not undergo any changes in pigmentation.
(C) Non-climacteric fruits synthesize starch rather than degrading it during ripening.
(D) Non-climacteric fruits lack an autocatalytic System 2 ethylene production pathway.

2001

56. Which term best describes senescence that is limited to the aerial parts of a herbaceous perennial plant while the underground rhizomes remain viable?
(A) Top senescence
(B) Deciduous senescence
(C) Overall senescence
(D) Progressive senescence

2008

57. The primary reason high relative humidity (RH) accelerates seed deterioration in storage is because it:
(A) Prevents the seed from respiring by blocking all gas exchange pores
(B) Increases equilibrium moisture content, stimulating fungal and metabolic activity
(C) Causes spontaneous mechanical cracking and fissuring of the protective seed coat
(D) Leaches out essential macro-nutrients and proteins from the storage endosperm

2005

58. Identify the correct statement regarding mucosal immunity in the context of edible vaccines.
(A) Edible vaccines bypass the mucosal immune system and act within the bloodstream
(B) They stimulate the production of Secretory

(B) Tyrosine and tryptophan
(C) Glutamine and asparagine
(D) Cysteine and methionine

2023

77. Which post-harvest chemical treatment directly blocks the conversion of ACC to ethylene?
(A) AVG (Aminoethoxyvinylglycine)
(B) AOA (Aminooxyacetic acid)
(C) 1-MCP (1-Methylcyclopropene)
(D) Cobalt ions ($Co^{\{2+1005\}}$)

2024

78. In the evaluation of post-harvest lipid oxidation, the activity of which enzyme is most directly correlated with the generation of free radicals and membrane damage?
(A) Superoxide dismutase
(B) Ascorbate peroxidase
(C) Lipoxygenase (LOX)
(D) Catalase

2001

79. The senescence of entire, mature monocarpic plants (like soybeans) can often be experimentally delayed by:
(A) Exposing the plant to continuous drought stress
(B) Removing the flowers or young pods before they develop
(C) Spraying the plant heavily with ethylene gas
(D) Increasing the soil salinity

2008

80. Consider the following statements regarding seed viability loss.
I. Membrane integrity loss is a primary cause of seed deterioration.
II. High seed moisture extends viability indefinitely.
III. Maillard reactions (non-enzymatic browning) occur in seeds during dry storage.
IV. Depletion of antioxidant defenses precedes viability loss.
V. Storing seeds at sub-zero temperatures rapidly kills orthodox seeds.
Which of the above statement(s) is/are CORRECT?
(A) I, III, IV and V
(B) I, II and IV
(C) I, II, III and V
(D) I, III and IV

2004

81. Transgenic modification using antisense RNA to suppress ACC oxidase (ACO) in cantaloupes results in fruits that:
(A) Show delayed ripening and prolonged shelf life on the vine
(B) Overproduce ethylene and spoil rapidly
(C) Are completely resistant to fungal pathogens
(D) Exhibit severe chilling injury at room temperature

2008

82. Which cellular component provides the structural framework of the abscission zone prior to organ shedding?
(A) A layer of rapidly dividing meristematic cells with heavily lignified walls
(B) A solid band of sclerenchyma fibers providing mechanical support to the petiole
(C) A separation layer of small cells that respond to ethylene by secreting enzymes
(D) An expansion of spongy mesophyll cells that lack a developed middle lamella

2021

83. The failure of citrus fruits to undergo a respiratory burst during ripening confirms their classification as:
(A) Non-climacteric fruits
(B) Climacteric fruits
(C) Parthenocarpic fruits
(D) Pseudocarps

2019

84. Which environmental variable strictly dictates the equilibrium moisture content of a seed batch during open warehouse storage?
(A) Ambient carbon dioxide level
(B) Storage light intensity
(C) Atmospheric pressure
(D) Ambient relative humidity

2005

85. The application of 1-MCP is fundamentally a method of:
(A) Modifying the storage atmosphere by displacing oxygen
(B) Chemically inhibiting the perception of ethylene at the receptor level
(C) Coating the fruit surface to prevent water loss
(D) Sterilizing the fruit surface against post-harvest decay pathogens

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primary cell wall
(D) Mechanical crushing by expansion of surrounding parenchyma cells

2010

68. What is the fundamental difference between System 1 and System 2 ethylene production?
(A) System 1 is autocatalytic, while System 2 is auto-inhibitory in nature
(B) System 1 occurs only in roots, while System 2 occurs only in leaves
(C) System 1 uses ACC as a precursor, while System 2 utilizes strictly IAA
(D) System 1 is vegetative and auto-inhibitory; System 2 is autocatalytic

2023

69. The breakdown of complex carbohydrates during post-harvest storage of potatoes at low temperatures (cold sweetening) leads to the undesirable accumulation of:
(A) Amylopectin
(B) Reducing sugars (glucose and fructose)
(C) Lignin
(D) Cellulose

2006

70. Given below are two lists. Match the physiological index of maturity in List I with the corresponding crop in List II.
List I: (Maturity Index)
P. Juice content and Brix-to-acid ratio
Q. Shell hardness and splitting
R. Black layer formation
S. Silking to harvest thermal time (Growing Degree Days)
List II: (Crop)
1. Maize (Corn)
2. Citrus
3. Sweet corn/peas
4. Macadamia/Walnut
(A) P-3, Q-1, R-4, S-2
(B) P-2, Q-3, R-1, S-4
(C) P-2, Q-4, R-1, S-3
(D) P-1, Q-4, R-2, S-3

2024

71. The "rin" (ripening inhibitor) mutant of tomato fails to ripen normally primarily because it has a mutation in a gene encoding a:
(A) ACC synthase enzyme involved in ethylene production
(B) Polygalacturonase enzyme involved in cell wall softening
(C) Ethylene receptor (ETR1) involved in hormone perception
(D) MADS-box transcription factor required for ripening activation

2001

72. Which environmental condition is the LEAST relevant for optimizing Controlled Atmosphere (CA) storage of apples?
(A) Photoperiod manipulation
(B) Temperature control
(C) Oxygen concentration
(D) Carbon dioxide concentration

2007

73. Identify the INCORRECT pair regarding enzymes and their functions in fruit softening.
(A) Pectin methylesterase - Demethylates pectin chains
(B) Lipoxygenase - Synthesizes hemicellulose cross-links
(C) Polygalacturonase - Cleaves alpha-1,4-galacturonan linkages
(D) Cellulase - Degrades the cellulose microfibril network

2014

74. Which process most accurately characterizes the physiological basis of cut flower bending (bent neck) in roses?
(A) Complete loss of geotropism due to localized auxin accumulation
(B) Xylem water potential depletion caused by bacterial plugging
(C) Excessive lignification of the pedicel preventing natural flexure
(D) Premature ethylene burst in the petals leading to rapid wilting

2006

75. Which statement best distinguishes between a mutant lacking ACC synthase and a mutant with a non-functional ETR1 receptor?
(A) The ACS mutant ripens with exogenous ethylene; the ETR1 mutant does not
(B) The ACS mutant cannot ripen at all; the ETR1 mutant will ripen naturally
(C) Both mutants will ripen normally following treatment with 1-MCP gas
(D) Neither mutant possesses the genetic capacity to ever synthesize ethylene

2018

76. During leaf senescence, nitrogen remobilization involves the conversion of amino acids into specific transport forms, primarily:
(A) Proline and betaine

NODIA

2005

95. The molecular regulator responsible for integrating developmental signals and abiotic stress to initiate leaf senescence via the promotion of abscisic acid signaling is often a member of which transcription factor family?
(A) MADS-box
(B) NAC
(C) LEAFY
(D) WUSCHEL

2016

96. What causes the loss of green color during the ripening of most climacteric fruits?
(A) The synthesis of green-absorbing anthocyanins within the central vacuole
(B) The irreversible structural conversion of chlorophyll directly into carotenoids
(C) The deposition of structural lignin over the chloroplasts and thylakoids
(D) Unmasking of pre-existing carotenoids through chlorophyll degradation

2022

97. In floral senescence, the wilting of ephemeral flowers like Ipomoea (Morning Glory) is uniquely characterized by:
(A) Rapid autophagy and nuclease up-regulation causing collapse within a day
(B) Being completely independent of programmed cell death or vacuolar collapse
(C) An extreme sensitivity to endogenous gibberellins and related growth hormones
(D) The physical shedding of fully turgid petals without any signs of wilting

2007

98. Which biochemical process is an immediate consequence of the respiratory climacteric in fruits?
(A) Drastic depletion of internal oxygen, leading to immediate fermentation
(B) Complete cessation of all metabolic activity within the fruit parenchyma
(C) Generation of ATP for the synthesis of ripening-related enzymes and pigments
(D) Reversal of starch hydrolysis back into amylose and other complex starches

2013

99. The "Never-ripe" (Nr) mutant in tomato was crucial for understanding fruit ripening because it demonstrated that:
(A) Ethylene perception is mediated by receptors whose mutation blocks ripening
(B) Ripening can occur perfectly without any ethylene or other gaseous cues
(C) Polygalacturonase is the sole enzyme responsible for the ripening process
(D) Tomatoes are naturally non-climacteric fruits despite their ethylene burst

2022

100. Given below are two statements, one is labelled as Assertion (A) and the other is labelled as Reason (R):
Assertion (A): The application of 1-MCP to climacteric fruits effectively delays ripening.
Reason (R): 1-MCP strongly binds to the ACC synthase enzyme, competitively inhibiting the production of ACC.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2002

101. Which morphological change typically indicates harvestable maturity for root crops like carrots and radishes?
(A) The onset of massive secondary flowering known as bolting in the crop
(B) Attainment of a root diameter and color standard required by the market
(C) Complete death of all above-ground foliage through natural senescence
(D) Formation of a suberized abscission layer at the stem-root junction point

2018

102. Which post-harvest modification strategy relies heavily on the selective permeability of polymer films to respiratory gases?
(A) Cold storage
(B) Modified Atmosphere Packaging (MAP)
(C) Hypobaric storage
(D) Active Controlled Atmosphere

2004

103. In seed storage, Orthodox seeds are defined by their ability to:
(A) Tolerate extreme desiccation and freezing without losing viability
(B) Only survive if seed moisture is maintained above 40% during storage
(C) Germinate immediately upon harvest without exhibiting any seed dormancy
(D) Resist structural lipid peroxidation indefinitely under ambient conditions

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2015

104. Recalcitrant seeds lose viability rapidly post-harvest primarily because they:
(A) Have exceptionally thick, impermeable seed coats that prevent water entry
(B) Undergo spontaneous fermentation when stored at typical room temperatures
(C) Lack any internal nutrient reserves or embryonic storage tissues for growth
(D) Are susceptible to desiccation injury and cannot be dried to low moisture

2025

105. During the post-harvest storage of grains, moisture migration within the silo is usually driven by:
(A) Temperature gradients causing convection currents that carry moisture
(B) Capillary action of the grain pericarp within the bulk storage medium
(C) Rapid starch hydrolysis occurring in the center of the stored grain mass
(D) High external carbon dioxide levels resulting from grain and insect respiration

2003

106. Ethylene biosynthesis is autocatalytic during fruit ripening. This means that:
(A) Ethylene suppresses its own receptors through a negative feedback loop
(B) Ethylene acts to rapidly degrade ACC synthase and related biosynthetic enzymes
(C) Ethylene perception triggers up-regulation of ACS and ACO transcription
(D) Ethylene chemically converts itself into complex polyamines during maturation

2005

107. The degradation of primary cell wall hemicelluloses during fruit softening involves the synergistic action of:
(A) Xyloglucan endotransglycosylase (XET) and expansins
(B) Chlorophyllase and PAO
(C) Lipoxygenase and phospholipase D
(D) ACC synthase and ACC oxidase

2017

108. Which compound is universally utilized in floral preservatives to lower the pH and limit bacterial growth?
(A) Sodium chloride
(B) Potassium permanganate
(C) Calcium carbonate
(D) Citric acid

2005

109. Potassium permanganate ($KMnO_4$) is often included in the packaging of horticultural crops because it:
(A) Functions as a potent fungicide against Botrytis
(B) Chemically oxidizes and removes free ethylene gas from the storage atmosphere
(C) Irreversibly binds to the ethylene receptors in the fruit peel
(D) Synthesizes artificial fruit aromas

2025

110. Given below are two lists. Match the molecular technique in List I with its specific application in List II.
List I: (Molecular Technique)
P. Antisense technology against PG gene
Q. Overexpression of SAM hydrolase
R. RNAi targeting ACC oxidase
S. SAG12-IPT transformation
List II: (Specific Application)
1. Delays leaf senescence by auto-producing cytokinin
2. Prevents the conversion of ACC to ethylene
3. Reduces cell wall softening by blocking polygalacturonase
4. Depletes the precursor SAM, preventing ethylene synthesis
(A) P-3, Q-1, R-2, S-4
(B) P-2, Q-4, R-3, S-1
(C) P-3, Q-4, R-2, S-1
(D) P-1, Q-2, R-4, S-3

2011

111. Which event is considered a hallmark of the irreversible execution phase of programmed cell death (PCD) in plants?
(A) Tonoplast rupture and release of vacuolar hydrolases into the cytosol
(B) Mild drought stress resulting in temporary loss of leaf turgor pressure
(C) Reversible stomatal closure mediated by the accumulation of abscisic acid
(D) Increased synthesis of abscisic acid and other stress-related hormones

2001

112. Senescence-associated genes (SAGs) are generally downregulated by which environmental intervention?
(A) Extended periods of darkness
(B) Application of exogenous cytokinin
(C) Severe nitrogen deficiency
(D) Infection by necrotrophic pathogens

NODIA

2022

113. An accumulation of which reactive species strongly correlates with the initiation of both aging and programmed senescence in plant tissues?
(A) Molecular nitrogen (N_2)
(B) Reactive oxygen species (ROS) like H_2O_2
(C) Simple sugars
(D) Free amino acids

2010

114. Why is the expression of senescence-associated genes often delayed in the source leaves of sink-deprived plants (e.g., plants where flowers are removed)?
(A) Sink removal causes sugar buildup in leaves, suppressing the trigger
(B) Removing flowers or pods actively kills the surrounding phloem tissue
(C) The roots instantly stop taking up water from the soil environment
(D) Leaves undergo rapid abscission instead of natural programmed senescence

2006

115. During the post-harvest storage of fresh vegetables, high respiration rates are generally correlated with:
(A) Increased shelf life and flavor enhancement through sugar accumulation
(B) Enhanced frost tolerance during the early stages of winter storage
(C) Accumulation of starch within the storage parenchyma of the vegetable
(D) Rapid loss of marketable quality and a significant shortening of shelf life

2013

116. Which physiological state describes a temporary halt in seed germination due to unfavorable environmental conditions, despite the seed being fully viable and non-dormant?
(A) Quiescence
(B) True dormancy
(C) Recalcitrance
(D) Senescence

2005

117. In the Yang cycle, the sulfur atom originally provided by methionine is:
(A) Incorporated directly into the final structure of the ethylene molecule
(B) Converted into a sulfate ion and sequestered within the central vacuole
(C) Recycled back to methionine via the methylthioadenosine salvage pathway
(D) Lost as sulfur dioxide gas through the stomatal pores of the plant

2018

118. Which statement best reflects the functional relationship between ethylene and silver (Ag^+) ions?
(A) Silver ions block the ethylene receptor, preventing signal transduction
(B) Silver ions catalyze the conversion of ACC to ethylene
(C) Silver ions rapidly oxidize ethylene into carbon dioxide
(D) Silver ions promote the transcription of ACC oxidase

2012

119. A defining characteristic of the progressive senescence pattern seen in wheat is that it:
(A) Begins in older basal leaves and moves upward to the flag leaf
(B) Begins at the flag leaf and moves downward to the older basal leaves
(C) Is synchronized by autumn temperatures regardless of the plant's age
(D) Moves strictly basipetally from the younger tissues to the older tissues

NODIA

2006

120. Consider the following statements regarding the physiology of edible vaccines.
I. They require highly purified antigens to be injected into the plant.
II. Transgenic plants express the antigen in their edible tissues.
III. They eliminate the risk of transgene escape to wild relatives.
Which of the above statements are INCORRECT?
(A) I and II
(B) I and III
(C) II and III
(D) I, II and III

2021

121. The selection of an ideal plant system for producing edible vaccines generally favors crops that:
(A) Require mandatory cooking before consumption to preserve the antigen
(B) Can be consumed raw to prevent heat denaturation of the vaccine protein
(C) Have high concentrations of toxic alkaloids to prevent pest damage
(D) Possess an exceptionally long vegetative phase without ever flowering

2011

194. In the molecular regulation of senescence, the NAC transcription factor family member ORE1 acts as a positive regulator of senescence. ORE1 expression is heavily suppressed in young leaves by:
(A) High levels of endogenous ethylene
(B) Specific microRNAs, primarily miR164
(C) Rapid starch accumulation
(D) Heavy lignification of the nucleus

2010

195. Which of the following is an advantage of using Modified Atmosphere Packaging (MAP) over Controlled Atmosphere (CA) storage?
(A) MAP is less expensive and maintains the atmosphere during transport
(B) MAP provides real-time computerized control over internal gas levels
(C) MAP completely prevents chilling injury in sensitive tropical fruits
(D) MAP can rapidly reduce the temperature without mechanical cooling

2007

196. Why is temperature management (the cold chain) considered the most critical factor in post-harvest handling?
(A) Decreasing temperature exponentially slows respiration and decay
(B) It strictly sterilizes the produce surface against fungal spores
(C) It chemically alters the flavor profile to be extremely sweet
(D) It prevents the production of all volatile aromas and esters

2018

197. The presence of excessive moisture on the surface of harvested seeds or fruits (free water) primarily leads to rapid post-harvest deterioration by:
(A) Dissolving the cellulose cell walls through hydrolytic reactions
(B) Altering osmotic potential causing instantaneous cellular bursting
(C) Providing a microenvironment for the growth of fungal spores
(D) Blocking the ethylene receptors and preventing hormone perception

2015

198. The primary function of the middle lamella in a fruit is to cement adjacent cells together. It is heavily rich in:
(A) Pectin
(B) Cellulose
(C) Lignin
(D) Suberin

2011

199. What happens biochemically during the "climacteric peak"?
(A) PFK (Phosphofructokinase) activity is inhibited completely at the peak
(B) Up-regulation of enzymes driving an intense spike in CO_2 evolution
(C) The fruit completely ceases all oxygen uptake from the environment
(D) Ethylene strictly acts as a competitive inhibitor of pome respiration

2024

200. Given below are two lists. Match the edible vaccine component in List I with its description in List II.
List I: (Component)
P. Mucosal immunity
Q. Bio-encapsulation
R. CTB (Cholera Toxin B)
S. Transgenic expression
List II: (Description)
1. Commonly used as an adjuvant and antigen carrier in edible vaccines
2. Protection provided by the rigid plant cell wall against stomach acids
3. The primary defense mechanism triggered in the gastrointestinal and respiratory tracts (sIgA)
4. The genetic mechanism by which the plant produces the foreign antigen
(A) P-3, Q-2, R-1, S-4
(B) P-4, Q-1, R-2, S-3
(C) P-3, Q-1, R-4, S-2
(D) P-2, Q-3, R-1, S-4

2022

201. The physiological abscission of leaves is preceded by the formation of a protective layer on the main stem side of the separation zone. This layer is typically infused with:
(A) Suberin and lignin
(B) Starch
(C) Free amino acids
(D) Pectin

2011

202. A seed that loses viability rapidly, such as the seed of a mango or a rubber tree, cannot be stored in standard gene banks primarily because:
(A) It requires constant illumination to survive during storage periods

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(A) When the fruit is young and tender with soft, unformed seeds
(B) When the seeds are fully hard, mature, and completely dry
(C) When the fruit is physiologically mature with heavily lignified skin
(D) When the parent vine completely senesces and stops all growth

2010

132. The development of mucosal immunity via edible vaccines relies on the uptake of the antigen by specialized cells in the gut epithelium known as:
(A) M cells (Microfold cells)
(B) Guard cells
(C) Macrophages
(D) Erythrocytes

2008

133. The enzyme complex primarily responsible for the controlled dismantling of proteins into transportable amino acids during leaf senescence is:
(A) The 26S proteasome and various vacuolar proteases
(B) ACC synthase and ACC oxidase enzyme complex
(C) Rubisco activase and associated chaperone proteins
(D) Glutamine synthetase and glutamate dehydrogenase

2015

134. A fruit that demonstrates a non-climacteric ripening pattern is typically insensitive to exogenous ethylene treatments in terms of:
(A) Degreening of the peel
(B) Autocatalytic stimulation of its own ethylene production
(C) Hastening of fungal decay
(D) Initiation of leaf abscission

2003

135. In cut flower physiology, carbohydrate depletion can be effectively mitigated post-harvest by:
(A) Supplying a low concentration of sucrose in the holding solution
(B) Increasing the ambient temperature
(C) Treating the flowers with high levels of abscisic acid
(D) Completely removing all remaining foliage

2006

136. Which structural change during fruit ripening is responsible for the transition of the fruit's texture from hard to soft and melting?
(A) Lignification and secondary thickening of the mesocarp cells
(B) Extensive deposition of cutin on the outer epidermal layers
(C) Aggregation of starch granules within the fruit's amyloplasts
(D) Hydrolysis and solubilization of pectic substances in the middle lamella

2003

137. Which statement accurately describes a major post-harvest challenge associated with modifying the atmosphere (MAP) to extremely low oxygen levels (e.g., $<1\%$)?
(A) The fruit undergoes rapid and unchecked photorespiration
(B) Fruit shifts to anaerobic respiration, producing off-flavors
(C) Ethylene biosynthesis increases exponentially due to low oxygen
(D) The fruit becomes excessively hard and develops a woody texture

2010

138. The physiological disorder "water core" in apples is primarily caused by:
(A) Severe fungal infection occurring during the storage period
(B) Freezing injury in the orchard environment prior to harvest
(C) Excessive transpiration leading to severe tissue desiccation
(D) Intercellular sorbitol accumulation instead of fructose conversion

2007

139. Polyamines such as spermine and spermidine delay senescence. This is biochemically associated with their ability to:
(A) Actively stimulate the PAO pathway and chlorophyll breakdown
(B) Compete for the SAM precursor shared with ethylene biosynthesis
(C) Irreversibly bind to the CTR1 protein and inhibit signal flow
(D) Cleave the ACC molecule into inactive fragments and byproducts

NODIA

2001

140. Arrange the following events in the ethylene biosynthesis pathway in the correct sequence:
I. Conversion of ACC to Ethylene
II. Synthesis of S-adenosylmethionine (SAM)
III. Conversion of SAM to ACC
IV. Activation of methionine by ATP

(A) IV, II, III, I
(B) II, IV, III, I
(C) IV, III, II, I
(D) II, III, IV, I

2018

141. The expression of the SAG12 gene is heavily utilized as a molecular marker because it is:
(A) Expressed constitutively in all plant tissues from seedling to death
(B) Induced strictly by mechanical wounding or pathogenic attack events
(C) Specific to age-dependent leaf senescence and not induced by stress
(D) The primary gene encoding the ACC oxidase enzyme in leaf tissues

2007

142. The "stay-green" trait observed in certain crop varieties (like sorghum) during terminal drought stress is generally an advantage because it:
(A) Prevents the grain from reaching physiological maturity or dry weight
(B) Maintains active photosynthesis longer to increase yield under stress
(C) Completely shuts down the ethylene response pathway in all tissues
(D) Accelerates the shedding of lower leaves to conserve water and nutrients

2017

143. During seed deterioration, the loss of which cellular component's integrity is measured indirectly by electrical conductivity tests on seed leachates?
(A) The nuclear envelope
(B) The cell wall
(C) The plasma membrane
(D) The vacuolar membrane

2011

144. Which factor is considered an intrinsic (internal) determinant of seed viability during post-harvest storage?
(A) Initial seed moisture content and genetic makeup
(B) Relative humidity of the storage room
(C) Composition of the storage atmosphere
(D) Fluctuations in warehouse temperature

2021

145. In post-harvest physiology, the "Q10 temperature coefficient" generally states that for non-chilling-sensitive crops, biological reaction rates:
(A) Double or triple for every $10^{\circ}C$ increase in temperature
(B) Halve for every $10^{\circ}C$ increase in temperature
(C) Remain completely stable across any $10^{\circ}C$ range
(D) Increase by exactly 10% for every $1^{\circ}C$

2014

146. Which characteristic represents a significant difference between chlorophyll degradation in senescing leaves versus ripening fruit?
(A) Leaf degradation aims at remobilization; fruit unmasks pigments
(B) Leaves use the PAO pathway while fruits use a different pathway
(C) Fruit degradation never involves forming fluorescent catabolites
(D) Leaves require exogenous ethylene for the process while fruits do not

2009

147. A primary limitation of using hypobaric (low pressure) storage for commercial fruits is:
(A) It drastically accelerates ethylene accumulation
(B) It causes rapid and severe oxygen toxicity
(C) It is extremely expensive to construct and maintain the physical facilities
(D) It encourages the proliferation of aerobic fungi

2001

148. Identify the correct pair regarding the molecular approaches to delayed ripening.
(A) RNAi of ACO - Inhibits the final step of ethylene biosynthesis
(B) Antisense PG - Reduces ethylene production
(C) Antisense ACS - Reduces cell wall softening independently of ethylene
(D) Transgenic SAM hydrolase - Directly destroys the ethylene receptor

2008

149. Why is the tomato commonly used as a model organism for studying fleshy fruit ripening?
(A) It has a small genome, easy transformability, and known mutants
(B) It is genetically non-climacteric and entirely independent of ethylene
(C) Its ripening cycle spans more than two years for long-term study
(D) It utilizes the alternative oxidase pathway for all respiration

2024

150. Given below are two statements, one is labelled as Assertion (A) and the other is labelled as Reason (R):

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Assertion (A): Climacteric fruits must be harvested only after they have reached full consumer ripeness on the tree.
Reason (R): Climacteric fruits have the capacity to undergo autocatalytic ethylene production even after harvest.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2004

151. Which statement best encapsulates the "source-sink" relationship during monocarpic senescence?
(A) Leaves act as nutrient sources for developing seeds (the sinks)
(B) Developing seeds act as powerful nutrient sources for expanding roots
(C) Senescing leaves import massive amounts of carbohydrates from meristems
(D) Vascular tissue becomes a major sink for lignin, killing the plant

2018

152. Post-harvest diseases in fruits are often accelerated by which physiological change during ripening?
(A) A decrease in cell wall integrity and a rise in soluble sugars
(B) An increase in the synthesis of fungitoxic phenolic compounds
(C) The massive lignification of epidermal tissues
(D) A complete halt in cellular respiration

2002

153. What specific role does aminooxyacetic acid (AOA) play in post-harvest chemistry?
(A) It blocks the ethylene receptor competitively
(B) It acts as an inhibitor of ACC synthase, similar to AVG
(C) It enhances the synthesis of polygalacturonase
(D) It stimulates the accumulation of abscisic acid

2015

154. The process of degreening citrus fruits post-harvest is commercially achieved by exposing them to:
(A) High concentrations of carbon dioxide
(B) Low, controlled concentrations of ethylene gas at optimal temperature and humidity
(C) Continuous far-red light
(D) Silver thiosulfate solutions

2013

155. Which of the following is considered the primary barrier to the long-term storage of cut rose flowers at $0^{\circ}C$?
(A) Occurrence of chilling injury and gray mold infection
(B) Uncontrollable and rapid starch retrogradation within petals
(C) Spontaneous abscission of thorns during the cooling process
(D) Severe light toxicity resulting from interior cooler lighting

2025

156. In transgenic crops developed for edible vaccines, the use of a tissue-specific promoter ensures that:
(A) Antigen synthesis in edible portions reduces vegetative metabolic drain
(B) Antigen expression occurs in leaves and roots but not in the fruit
(C) The plant becomes entirely resistant to all systemic herbicide treatments
(D) The vaccine acts instantly upon direct contact with the human skin

2008

157. During the senescence of a plant leaf, the rate of photosynthesis drops precipitously. This is primarily directly correlated with the degradation of:
(A) Structural cellulose fibers
(B) Ribulose-1,5-bisphosphate carboxylase/oxygenase
(C) Starch grains within amyloplasts
(D) Phospholipids in the thylakoid membrane

2023

158. The physiological phenomenon where isolated leaves senesce rapidly in darkness but remain green if exposed to light or cytokinins demonstrates that:
(A) Light and cytokinins are strict inhibitors of the Yang cycle pathway
(B) Senescence is negatively regulated by light and root-derived cytokinins
(C) Darkness physically tears apart the chloroplast membranes and thylakoids
(D) Isolated leaves lack any genetic capacity for natural programmed senescence

NODIA

2022

159. What is the fundamental principle behind using modified atmosphere packaging (MAP) for fresh-cut vegetables?
(A) Creating an absolute vacuum to stop all biological activity in the bag

2014

122. During the post-harvest handling of climacteric fruits, cold chain logistics primarily serve to:
(A) Halt entirely the biological aging process within the fruit tissue
(B) Lower respiration rates and delay the onset of the climacteric peak
(C) Sterilize the fruit surface against all known post-harvest pathogens
(D) Increase the conversion of starch to sugar using artificial enzymes

2003

123. The vascular occlusion that shortens the vase life of cut flowers is frequently exacerbated by:
(A) Tracheid cavitation caused by cutting stems in the air rather than underwater
(B) The application of citric acid to the vase water
(C) Storing flowers at near-freezing temperatures
(D) The accumulation of anthocyanins in the petal epidermal cells

2007

124. Which physiological process strictly defines "abscission"?
(A) The localized death of cells due to physical crushing or injury
(B) The shedding of organs following cell wall dissolution in a separation zone
(C) The progressive yellowing of a leaf caused by severe nitrogen starvation
(D) The uncontrolled bursting of a fruit while still attached to the vine

2014

125. One of the main biochemical pathways mediating the depletion of carbohydrates in stored root vegetables is:
(A) The Calvin cycle
(B) The oxidative pentose phosphate pathway and glycolysis
(C) The PAO pathway
(D) The Yang cycle

2025

126. High temperatures during the grain-filling period (terminal heat stress) result in forced maturity. This is physically manifested as:
(A) Shriveled grains with reduced starch deposition
(B) Increased grain size and higher yield
(C) Enhanced protein quality in the endosperm
(D) Delayed leaf senescence

2004

127. Which signaling molecule is primarily involved in the systemic acquired resistance (SAR) pathway and often accelerates localized necrotic lesions?
(A) Gibberellic acid
(B) Indole-3-butyric acid
(C) Salicylic acid
(D) Brassinolide

2003

128. What is the fundamental mechanism behind the action of antisense RNA technology in the Flavr Savr tomato?
(A) Antisense strand binds to target mRNA to form dsRNA that is degraded
(B) Antisense gene synthesizes a potent chemical inhibitor of polygalacturonase
(C) Antisense RNA directly edits the host DNA sequence in the nucleus
(D) Antisense RNA codes for an enzyme that reinforces the primary cell wall

2015

129. How does the application of exogenous auxins generally affect the leaf abscission zone?
(A) It reduces the sensitivity of the abscission zone to ethylene
(B) It drastically accelerates the formation of the separation layer cells
(C) It sensitizes the cells of the abscission zone to gaseous ethylene
(D) It rapidly hydrolyzes the middle lamella through enzyme activation

2001

130. Given below are statements regarding programmed cell death (PCD) in plant development.
I. PCD is essential for the formation of functional aerenchyma in waterlogged roots.
II. PCD is strictly an abnormal pathological response.
III. Xylem vessel element maturation requires PCD for complete hollowing out of the cell.
IV. PCD in plants involves DNA laddering and vacuolar collapse.
Which of the above statements are CORRECT?
(A) I, II and IV
(B) I, III and IV
(C) II, III and IV
(D) I, II and III

2018

131. Which of the following defines "commercial maturity" for a vegetable like zucchini (summer squash)?

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2002

168. To control the senescence of cut flowers, holding solutions are commonly formulated with sucrose. The primary role of this sucrose is to:
(A) Block the xylem vessels to prevent excessive water uptake and loss
(B) Substrate-inhibit the PAO pathway to prevent chlorophyll breakdown
(C) Provide a respirable substrate to replace carbohydrate reserves
(D) Drastically alter the petal color through the synthesis of pigments

2007

169. Identify the INCORRECT statement regarding lipid oxidation during seed storage.
(A) It generates free radicals that damage DNA and proteins.
(B) It is significantly accelerated by high temperature and high moisture.
(C) It primarily targets the highly saturated fatty acids in the cell membrane.
(D) Lipoxygenase is a key enzyme involved in initiating this process.

2018

170. Given below are statements regarding molecular approaches to shelf life.
I. RNAi can target multiple homologous genes simultaneously if designed correctly.
II. Antisense technology completely and irreversibly alters the plant's genomic DNA sequence for all traits.
III. Suppressing ACC synthase extends shelf life by preventing ethylene synthesis.
IV. Suppressing polygalacturonase directly blocks ethylene production.
V. Transgenic tomatoes with delayed ripening still require ethylene to eventually ripen fully.
Which of the above statements are INCORRECT?
(A) II and IV
(B) I, III and V
(C) I, II and IV
(D) II, III and V

2016

171. A major advantage of progressive senescence in cereal crops is that it allows the plant to:
(A) Maintain efficient upper leaves while recycling nutrients from older ones
(B) Survive extreme freezing temperatures during the vegetative growth phase
(C) Avoid all forms of programmed cell death throughout the entire life cycle
(D) Completely suppress the production of abscisic acid in the leaf tissues

2003

172. The degradation of chlorophyll results in colorless catabolites that are ultimately sequestered into which cellular compartment?
(A) The nucleus
(B) The central vacuole
(C) The endoplasmic reticulum
(D) The extracellular space

2005

173. What distinguishes the senescence of a flower from the senescence of a leaf?
(A) Flower senescence occurs to remobilize nitrogen specifically for roots
(B) Rapid and coordinated senescence occurs after pollination or lifespan
(C) Leaf senescence is entirely dependent on pollination of the flowers
(D) Flower senescence uniquely utilizes the PAO pathway for protein breakdown

2007

174. Which event immediately triggers a massive surge of ethylene production in specific orchids (e.g., Phalaenopsis) leading to rapid petal senescence?
(A) Exposure to a 12-hour photoperiod
(B) Emasculation or successful pollination
(C) A drop in ambient temperature by $5^{\circ}C$
(D) Accumulation of massive amounts of starch in the petals

2025

175. The physiological process of chilling injury involves oxidative stress. Which endogenous protective system is usually overwhelmed during this stress?
(A) The cellulase and polygalacturonase enzyme complex within the cell wall
(B) The antioxidant defense system including SOD, APX, and catalase
(C) The Yang cycle enzymes responsible for high levels of ethylene production
(D) The amyloplast synthesis pathway responsible for starch accumulation

2016

176. Which of the following is a key feature of "hermetic storage" for grain protection?
(A) Constant application of liquid nitrogen
(B) Maintenance of high oxygen levels to prevent mold
(C) Biological oxygen depletion and carbon

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dioxide rise by grain/insect respiration
(D) Continuous ventilation with ambient air to remove heat

2012

177. The term "climacteric minimum" refers to:
(A) The lowest respiration rate preceding the subsequent climacteric rise
(B) The lowest temperature a fruit can survive before the onset of freezing
(C) The minimum amount of ethylene required to trigger leaf death or decay
(D) The absolute zero of gas exchange observed in a dormant grain or seed

2019

178. During the post-harvest storage of sweet potatoes, they are often subjected to a "curing" process. The physiological purpose of this is to:
(A) Promote suberization and healing of wounds sustained during harvest
(B) Force the rapid conversion of all starch to sugar in the root tissue
(C) Induce a massive ethylene burst to soften the internal storage flesh
(D) Completely dry out the skin to prevent sprouting and fungal infection

2013

179. Which post-harvest dynamic is most uniquely prominent in the deterioration of leafy vegetables (e.g., spinach) compared to fleshy fruits?
(A) Rapid moisture loss (wilting) and rapid chlorophyll degradation (yellowing)
(B) Severe chilling injury at $10^{\circ}C$
(C) Spontaneous starch retrogradation
(D) Massive accumulation of complex esters

2022

180. Arrange the following events in the ripening process of a climacteric fruit in the correct sequence:
I. Autocatalytic ethylene production
II. Accumulation of threshold levels of System 1 ethylene
III. Activation of cell wall hydrolytic enzymes and pigment synthesis
IV. Sharp rise in respiration rate (climacteric peak)
(A) II, I, IV, III
(B) II, IV, I, III
(C) I, II, IV, III
(D) II, I, III, IV

2010

181. Why are polyamines theoretically capable of acting as anti-senescence chemicals?
(A) They aggressively inhibit the mitochondrial electron transport chain
(B) Basic molecules that stabilize membranes and compete for SAM
(C) They chemically destroy all endogenous ethylene molecules on contact
(D) They cross-link cellulose microfibrils making them totally indigestible

2025

182. A genetic approach to enhancing the vase life of cut flowers, similar to that used in tomatoes, involves transforming plants (e.g., carnations) with:
(A) Antisense PG constructs for cell wall modification and softening
(B) Antisense ACS or ACO constructs, or mutated ethylene receptors
(C) The Bt toxin gene for the prevention of post-harvest insect damage
(D) The cholera toxin B subunit used as an antigen or mucosal adjuvant

2005

183. Which morphological marker is typically used to identify physiological maturity in cereal crops like wheat and barley?
(A) Complete loss of green color in the peduncle below the head
(B) The grain becomes highly responsive to treatment with ethylene gas
(C) The onset of anthesis and subsequent pollination of the flowers
(D) The elongation of the coleoptile during the early germination phase

2013

184. The physiological disorder "hollow heart" in potatoes is fundamentally caused by:
(A) Prolonged exposure to extreme freezing temperatures during storage
(B) Rapid growth following stress causing internal tissue splitting
(C) Severe infection by the late blight pathogen during the storage phase
(D) Calcium deficiency in the apical meristem of the developing tuber

2008

185. In the evaluation of seed storage potential, what does "Harrington's rule of thumb" generally suggest regarding seed moisture and temperature?

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(A) Life halves for every 1% moisture or 5 degree C temperature increase
(B) Seed storage life doubles with every one percent increase in moisture
(C) Storage temperature is irrelevant if moisture is kept below 20 percent
(D) Seed viability requires alternating warm and freezing storage cycles

2014

186. Which biochemical mechanism primarily drives the sweetening of fruits during ripening?
(A) The synthesis of new starch granules within the mesocarp tissue
(B) The conversion of stored organic acids into complex polysaccharides
(C) Enzymatic hydrolysis of stored starch into simple, sweet sugars
(D) The breakdown of cellulose into simple sugars via cellulase action

2010

187. An edible vaccine designed against Hepatitis B surface antigen (HBsAg) was successfully expressed in which common crop for raw consumption?
(A) Rice
(B) Potato (fed raw in clinical trials)
(C) Sugarcane
(D) Wheat

2014

188. Which cellular event strongly indicates that a plant cell is undergoing programmed cell death rather than necrotic death?
(A) Organized DNA cleavage and dismantling with intact membranes
(B) Random, uncontrolled bursting of the cell membrane due to injury
(C) A massive and instant halt to all mitochondrial ATP production
(D) An immediate fusion of multiple adjacent cells into a syncytium

2016

189. During progressive leaf senescence, which nutrients are notably NOT remobilized and instead remain locked in the senescing leaf?
(A) Nitrogen and phosphorus
(B) Potassium and magnesium
(C) Calcium and boron
(D) Sulfur and zinc

2003

190. Given below are two statements, one is labelled as Assertion (A) and the other is labelled as Reason (R):
Assertion (A): Edible vaccines provide an efficient means of inducing mucosal immunity.
Reason (R): When consumed, the plant cell wall acts as a natural bio-encapsulation matrix, protecting the antigen from rapid degradation in the harsh stomach environment.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2018

191. A unique characteristic of senescence in deciduous trees is that the timing of massive leaf shedding is most directly cued by:
(A) Soil nutrient depletion occurring at the end of the summer season
(B) Shortening photoperiods and decreasing temperatures in the autumn
(C) Massive accumulation of ethylene strictly from neighboring trees
(D) A sudden spike in ambient carbon dioxide within the forest canopy

2012

192. Which metabolic process provides the energy and carbon skeletons required for the synthesis of secondary metabolites (like anthocyanins) during fruit ripening?
(A) The respiratory climacteric burst providing ATP and carbon skeletons
(B) Anaerobic fermentation occurring within the internal fruit tissues
(C) The rapid increase in photosynthetic activity of the outer fruit skin
(D) The complete suppression of the TCA cycle during the ripening phase

2005

193. The mechanism of post-harvest lipid oxidation fundamentally destabilizes the physical structure of:
(A) The cellulose microfibrils
(B) The starch grains
(C) The cellular and organellar lipid bilayer membranes
(D) The middle lamella

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(B) Natural respiration creates an equilibrium of low oxygen and high CO_2
(C) Constantly flushing the package with one hundred percent oxygen gas
(D) Sterilizing the vegetables with high-dose gamma radiation inside the bag

2006

160. Given below are two lists. Match the post-harvest disorder in List I with its characteristic visual symptom or cause in List II.
List I: (Post-harvest Disorder)
P. Chilling injury in bananas
Q. Bitter pit in apples
R. Water core in apples
S. Scald in apples
List II: (Visual Symptom/Cause)
1. Dark sunken lesions or browning of the peel at low temperatures
2. Sunken dark spots on the skin due to localized calcium deficiency
3. Translucent, water-soaked tissue around the core due to sorbitol accumulation
4. Browning of the epidermis due to oxidation of alpha-farnesene
(A) P-1, Q-2, R-3, S-4
(B) P-2, Q-1, R-4, S-3
(C) P-4, Q-3, R-2, S-1
(D) P-1, Q-3, R-2, S-4

2022

161. A critical regulatory node in ethylene signaling is the stabilization of EIN3. In the presence of ethylene, EIN3 is:
(A) Targeted for immediate destruction by the 26S proteasome complex
(B) Stabilized because the F-box proteins EBF1/EBF2 are degraded
(C) Transported completely out of the nucleus into the cytosol area
(D) Phosphorylated by CTR1 and subsequently targeted for destruction

2002

162. Which post-harvest dynamic strongly differentiates the physiology of cereal grains from fresh fleshy fruits?
(A) Grains have low moisture and metabolic rates compared to fleshy fruits
(B) Grains undergo a climacteric respiratory burst while fleshy fruits do not
(C) Grains completely lack lipids and thereby avoid all forms of oxidation
(D) Grains require continuous ethylene application to remain viable and healthy

2007

163. A key biochemical characteristic of the execution phase of programmed cell death (PCD) is the activation of:
(A) Metacaspases and specific endonucleases
(B) ACC synthases
(C) Chlorophyllases
(D) Starch synthases

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2002

164. The application of 1-MCP (1-Methylcyclopropene) is most effective when applied:
(A) Immediately before consuming the fruit
(B) Prior to the onset of the climacteric respiratory burst
(C) After the fruit has become overripe and soft
(D) Exclusively to the roots of the parent plant

2019

165. Which biological process is heavily relied upon to maintain the quality of dormant potato tubers and prevent sprouting during long-term storage?
(A) Application of ethylene at high temperatures to stimulate dormancy
(B) Maintaining low temperatures and applying sprout suppressants like CIPC
(C) Constant exposure to high-intensity light during the storage period
(D) Rapid dehydration to fifteen percent moisture using industrial driers

2005

166. A critical factor in assessing physiological maturity in legumes (e.g., soybeans) is:
(A) The pods turn entirely black and shatter spontaneously in the field
(B) Maximum dry weight is reached and pods lose their green color
(C) The seeds begin to germinate within the pod through vivipary events
(D) The plant initiates a second flush of flowers after the first harvest

2001

167. Which of the following explains why low O_2 concentrations (usually around 2%) in CA storage delay fruit ripening?
(A) Low oxygen levels aggressively kill all post-harvest fungal spores
(B) Low oxygen limits ethylene production by depriving the ACO enzyme
(C) Low oxygen levels rapidly and irreversibly destroy the ETR1 receptor
(D) Low oxygen forces the fruit to convert starch into structural lignin

(B) Lethal desiccation damage if dried below fifteen to thirty percent moisture
(C) It has a massive rate of auto-toxicity from inherent tissue alkaloids
(D) It completely lacks a seed coat to protect the internal embryonic mass

2016

203. Which process occurs extensively in the vascular tissues of cut flowers due to poor water quality, severely limiting vase life?
(A) Deposition of suberin by the xylem parenchyma leading to occlusion
(B) Spontaneous production of massive starch grains within the vessels
(C) Complete destruction of the phloem and companion cell complexes
(D) Hyper-accumulation of calcium and other divalent ions in the stem

2007

204. Which of the following is a primary physiological effect of treating climacteric fruits with high levels of exogenous carbon dioxide post-harvest?
(A) It irreversibly destroys the cellular DNA within the mesocarp
(B) Competitive inhibition of ethylene action and suppressed respiration
(C) Prevention of ripening even after returning to a normal atmosphere
(D) It causes an instant climacteric burst and rapid tissue softening

2012

205. Consider the following statements regarding senescence-associated genes (SAGs).
I. SAGs only encode destructive enzymes like nucleases and proteases.
II. Some SAGs encode proteins involved in nutrient remobilization and transport.
III. SAG expression is regulated entirely by ethylene, independent of age.
Which of the above statement(s) is/are CORRECT?
(A) I and III
(B) I
(C) II and III
(D) II

2015

206. In the post-harvest storage of onions and garlic, sprouting is a major cause of quality loss. Sprouting is strongly suppressed by:
(A) Application of maleic hydrazide and maintaining low humidity
(B) Storing them at extremely high humidity near one hundred percent
(C) Storing them at moderate temperatures with high internal ventilation
(D) Continuous treatment with exogenous ethylene gas to halt growth

2017

207. Which characteristic is most representative of a truly monocarpic plant?
(A) A single reproductive cycle followed by senescence and death
(B) Repeated flowering over many years before the plant finally senesces
(C) Shedding top leaves during winter with regrowth during the spring
(D) Reproduction strictly via vegetative runners and asexual propagation

2002

208. During the ripening of a tomato, the color shifts from green to red primarily due to:
(A) Degradation of chlorophyll and massive de novo synthesis of lycopene
(B) The conversion of starch to complex red polysaccharides
(C) The synthesis of anthocyanins in the central vacuole
(D) The unmasking of pre-existing red pigments in the cell wall

2017

209. Ethylene perception in plants utilizes a two-component signaling system conceptually similar to those found in:
(A) Archaea
(B) Fungi
(C) Bacteria
(D) Mammals

2001

210. Which post-harvest physiological mechanism is most directly linked to the development of off-flavors in overripe or improperly stored fruits?
(A) Anaerobic respiration due to extremely low internal oxygen levels
(B) Aerobic respiration climax leading to rapid energy consumption
(C) Excessive lipid peroxidation and the breakdown of membranes
(D) Rapid starch synthesis occurring within the storage parenchyma

2002

211. What is the fundamental difference between the action of AVG and the action of 1-MCP?

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(A) AVG blocks ACS biosynthesis; 1-MCP blocks receptor perception
(B) AVG blocks the receptor; 1-MCP blocks the biosynthetic pathway
(C) Both chemically destroy the ethylene molecule within the storage air
(D) Both operate strictly in non-climacteric fruits like citrus or grapes

2021

212. Which part of the leaf blade typically senesces first in monocots like wheat?
(A) The leaf tip and margins
(B) The base of the leaf blade near the sheath
(C) The midrib alone
(D) The entire leaf uniformly and instantaneously

2016

213. A significant molecular challenge in creating edible vaccines using plant systems is ensuring:
(A) Adequate and consistent expression of the antigen in the tissues
(B) The host plant is completely stripped of all native storage proteins
(C) The plant instantly undergoes programmed cell death upon harvest time
(D) The antigen causes immediate systemic resistance throughout the plant

2024

214. Which cellular structure remains morphologically intact until the very latest stages of leaf senescence, facilitating nutrient remobilization?
(A) The mitochondrion
(B) The chloroplast
(C) The central vacuole
(D) The rough endoplasmic reticulum

2003

215. Consider the following statements regarding the ripening of climacteric fruits.
I. Ethylene production shifts from auto-inhibitory (System 1) to autocatalytic (System 2).
II. The respiratory burst occurs synchronously with or slightly after the onset of the ethylene burst.
III. Fruit softening is caused by the synthesis of complex cellulose microfibrils.
IV. Color changes are strictly dependent on the accumulation of massive amounts of starch.
Which of the above statements are INCORRECT?
(A) I and II
(B) II and III
(C) III and IV
(D) I and IV

2008

216. Which chemical coating is frequently applied to harvested citrus fruits to reduce post-harvest transpiration and improve cosmetic appearance?
(A) Carnauba wax or synthetic resin waxes
(B) Calcium chloride
(C) Silver thiosulfate
(D) Salicylic acid

2012

217. In the context of seed deterioration, "accelerated aging" is a technique used primarily to:
(A) Predict vigor and longevity by subjecting seeds to stress conditions
(B) Induce early germination for significantly faster crop cycles in the field
(C) Quickly breed entirely new varieties using mutagenic chemical agents
(D) Force recalcitrant seeds to become orthodox through genetic engineering

2002

218. The expression of antisense RNA targeting ACC oxidase in tomatoes results in:
(A) Reduced ethylene production, delaying ripening and extending shelf-life
(B) Complete elimination of the fruit's ability to synthesize lycopene red
(C) Massive overproduction of ACC leading to subsequent fruit explosion
(D) The fruit ripening twice as fast compared to the original wild-type plant

2021

219. During programmed cell death (PCD) in the developmental context of a plant, the dead cells are often:
(A) Retained for functional roles like water transport or structural support
(B) Rapidly expelled from the plant body through the abscission process
(C) Converted back into active meristematic stem cells for future growth
(D) Re-inflated with water to act as internal reserve storage for the roots

2021

220. Which factor is most directly responsible for the massive generation of reactive oxygen species (ROS) during severe post-harvest chilling injury?
(A) Uncoupling of the electron transport chain due to phase transitions
(B) Extreme activation of the Calvin cycle during the cooling process

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(C) Rapid synthesis of ethylene gas and related biosynthetic proteins
(D) Over-accumulation of toxic heavy metals within the fruit tissue

2006

221. The stage of "physiological maturity" in fleshy fruits (like a tomato) is conceptually closest to the stage where:
(A) The fruit is fully red and soft, ready for immediate consumption
(B) Fully developed seeds allowing ripening after fruit detachment
(C) The fruit is first formed on the flower during the fruit set phase
(D) The fruit begins to physically rot due to post-harvest pathogens

2021

222. The most prevalent volatile organic compound responsible for the distinct aroma of a ripening banana is:
(A) Isoamyl acetate
(B) Alpha-farnesene
(C) Limonene
(D) Menthol

2019

223. Which molecular event directly allows the ripening-related transcription factor RIN (RIPENING INHIBITOR) to bind to the promoters of its target genes in tomatoes?
(A) Epigenetic demethylation of the target gene promoters
(B) Massive hypermethylation across the entire plant genome
(C) Complete destruction of all small RNAs in the cytoplasm
(D) Binding to the CTR1 kinase protein in the signaling path

2007

224. A practical method to minimize vascular occlusion caused by air embolisms in cut flowers is to:
(A) Cut the stem ends underwater
(B) Burn the stem ends
(C) Heavily crush the stem ends with a hammer
(D) Store the stems in a dry, hot environment

2013

225. Given below are statements concerning post-harvest fruit softening.
I. Softening is primarily a cell wall modification process.
II. Pectin methylesterase removes methyl groups from pectins, making them accessible to polygalacturonase.
III. Expansins loosen the non-covalent network between cellulose and hemicellulose.
IV. Extensive lignification causes the melting texture of ripe peaches.
V. Cellulases act on the xyloglucan-cellulose framework.
Which of the above statements are CORRECT?
(A) I, II, III and V
(B) II, III, IV and V
(C) I, III, IV and V
(D) I, II, IV and V

2009

226. What physiological role does the formation of plastoglobuli serve during chloroplast dismantling in senescing leaves?
(A) Storage depots for lipid breakdown products from the membranes
(B) They act as massive starch storage units for the next generation
(C) They perform photosynthesis when the thylakoids are destroyed
(D) They synthesize the nucleases needed for nuclear dismantling stages

2004

227. In post-harvest physiology, what defines a "climacteric" vs "non-climacteric" response to exogenous ethylene applied to mature green fruit?
(A) Ethylene triggers the peak in one but only transient respiration in another
(B) Exogenous ethylene has absolutely zero effect on any climacteric fruit
(C) Non-climacteric fruits respond by massive autocatalytic ethylene production
(D) Both types respond identically by shutting down cellular respiration entirely

2022

228. In sweet corn post-harvest:
(A) Sucrose converts to starch, causing sweetness loss if not cooled
(B) Starch rapidly hydrolyzes into simple sugar, making it much sweeter
(C) Sugars instantly oxidize into structural lignin within the kernels
(D) Starch is converted into structural cellulose in the outer pericarp

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2021

229. A significant advantage of employing RNAi over antisense technology for suppressing ripening genes is that RNAi:

(A) Stronger knockdown of target genes due to its catalytic mechanism

(B) Operates entirely outside the plant cell in the soil environment

(C) Replaces the target gene with a superior synthetic gene construct

(D) Causes the fruit to grow indefinitely without ever reaching maturity

NODIA

2012

230. During the natural senescence of a plant leaf, what happens to the stomatal conductance and transpiration rate?

(A) They decrease as guard cells lose functionality and responsiveness

(B) They both increase dramatically to cool the senescing leaf tissue

(C) They remain exactly the same as in a young, actively growing leaf

(D) Stomata lock in a completely wide-open state throughout the day

****

ANSWERS

1. (A) A regulated, genetically programmed sequence of events leading to death
Senescence in plants is a highly regulated, genetically programmed developmental stage aimed at nutrient recycling and survival. Unlike passive aging, which involves random damage accumulation, senescence utilizes complex signaling pathways and specific genes to dismantle cellular structures. This process ensures that mobile nutrients are remobilized from older tissues to younger organs or developing seeds effectively during the plant life cycle.

2. (C) An unprogrammed cell death resulting from acute physical or chemical injury
Necrosis represents a passive and unprogrammed form of cell death that occurs following severe external stress or acute injury. It typically involves the rapid swelling and rupture of cells, leading to inflammation and tissue decay. In contrast, programmed cell death is a controlled biological sequence involving specialized enzymes and signal transduction pathways for specific developmental goals or defense against pathogens.

3. (A) Senescence progresses upward from the older basal leaves to the younger upper leaves
Progressive senescence is a distinct developmental pattern where the aging process begins at the base of the plant and moves toward the top. Older leaves at the bottom yellow and die first as their nutrients are remobilized to support the growth of younger, developing foliage at the apex. This sequential strategy optimizes resource use throughout the various growth stages.

4. (D) Synchronous or deciduous senescence
Deciduous trees exhibit a synchronous pattern of senescence triggered primarily by environmental cues like decreasing day length and temperature. This coordinated shedding of leaves allows the plant to conserve water and energy during unfavorable winter conditions. The process involves precise hormonal changes and the formation of abscission layers at the base of petioles before the leaves eventually fall to ground.

5. (B) The developing flowers and seeds
In monocarpic plants, the entire organism undergoes senescence following a single reproductive event. This process involves the massive remobilization of nitrogen, phosphorus, and other essential minerals from vegetative organs like leaves and stems. These harvested nutrients are transported through the phloem to the developing flowers and seeds, ensuring successful reproduction and high-quality progeny for the next plant generation.

6. (C) Nitrogen
RuBisCO is the most abundant protein in plant leaves, serving as a primary reservoir of organic nitrogen. During the senescence process, this enzyme is broken down by specialized proteases into transportable amino acids. These nitrogenous compounds are then remobilized from the aging foliage to growing sinks, such as developing seeds or younger leaves, to sustain overall plant productivity and development.

7. (D) ACC synthase (ACS)
The conversion of S-adenosylmethionine to 1-aminocyclopropane-1-carboxylic acid represents the committed and often rate-limiting step in ethylene biosynthesis. This reaction is catalyzed by the enzyme ACC synthase within the Yang cycle. Regulating the activity and expression of this enzyme is crucial for controlling various plant processes, including fruit ripening, flower senescence, and responses to diverse environmental stress factors.

8. (A) 5-Methylthioadenosine (MTA)
High rates of ethylene production require a constant supply of methionine, which is limited in plant cells. The Yang cycle solves this by recycling 5-methylthioadenosine, a byproduct of the ACC synthase reaction, back into methionine. This salvage pathway allows plants to sustain significant ethylene synthesis during critical developmental stages like fruit ripening without depleting their internal pool of essential sulfur.

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are structured as homodimers that bind ethylene molecules via a copper cofactor. Understanding their specific cellular location is vital for mapping the signal transduction pathway, which ultimately regulates the expression of ethylene-responsive genes in the nucleus through downstream components.

28. (C) Chilling injury
Bananas are tropical fruits that are highly sensitive to low temperatures above their freezing point. Storing them below approximately thirteen degrees Celsius leads to chilling injury, which manifests as skin browning, pitting, and a failure to ripen properly. This physiological disorder is caused by changes in membrane fluidity and the subsequent disruption of cellular metabolism, resulting in a loss of quality.

29. (D) Plastoglobuli
As chloroplasts transition into gerontoplasts during leaf senescence, the internal thylakoid membranes are dismantled and their lipid components are recycled. These lipids, along with chlorophyll degradation products, accumulate in spherical structures called plastoglobuli. These structures increase in size and number as the organelle breaks down, serving as temporary storage sites for hydrophobic molecules before they are further processed or remobilized.

30. (C) II and III
Flower senescence patterns vary among species, with some exhibiting tepal abscission without significant wilting symptoms. Cytokinins are widely recognized for their ability to delay aging in cut flowers by maintaining cellular metabolism and reducing the rate of protein degradation. However, not all flowers rely on ethylene for wilting, as many species are classified as ethylene-insensitive during their natural senescence process.

31. (B) Plant cells do not undergo phagocytosis due to their rigid cell walls
While animal apoptosis concludes with the phagocytosis of apoptotic bodies by neighboring cells, the rigid cellulose cell wall of plants prevents this mechanism. Instead, plant programmed cell death typically involves the rupture of the central vacuole and the release of hydrolytic enzymes that digest the cytoplasm in situ. This autolytic process allows for the recycling of nutrients within the plant.

32. (C) The fruit meets the requirements of the consumer or market processor
Harvestable or commercial maturity is defined by the specific needs of the market rather than a strictly biological stage. For instance, some fruits are harvested when they are immature but crisp, while others must reach full ripeness. This stage ensures that the produce has the necessary quality, flavor, and shelf life to survive transportation and satisfy the ultimate consumer's preferences.

33. (A) Bacterial proliferation and formation of air embolisms in the xylem
The premature wilting of cut flowers is often caused by the physical blockage of the xylem vessels, which prevents water from reaching the petals. This vascular occlusion is primarily driven by the rapid growth of bacteria in the vase water and the entry of air bubbles during the cutting process. These obstructions disrupt the continuous water column needed for maintaining cell turgor.

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34. (C) Antisense RNA technology targeting polygalacturonase
The Flavr Savr tomato was the first genetically engineered food crop to be commercially released. It utilized antisense RNA technology to specifically downregulate the expression of the polygalacturonase gene. By reducing the levels of this enzyme, the rate of pectin degradation in the cell wall was slowed, resulting in a fruit that remained firm for a longer period after reaching ripeness.

35. (A) Low seed moisture content and sub-zero temperatures
The longevity of orthodox seeds in germplasm banks is maximized by reducing their metabolic rate to the lowest possible level. This is achieved by drying the seeds to a low moisture content and storing them at sub-zero temperatures. Such conditions significantly slow down the chemical reactions and biological processes that lead to the gradual loss of seed viability over time.

36. (D) Edible surface coatings like carnauba wax applied to the skin
Applying edible coatings to the surface of fruits creates a physical barrier that restricts the diffusion of gases such as oxygen, carbon dioxide, and water vapor. This modification mimics the effects of a controlled atmosphere by slowing

subjecting them to extreme stress. Seeds are typically exposed to high temperatures and high relative humidity for a short duration, which mimics the natural deterioration process at an increased rate. This allows researchers to predict how well the seeds will maintain viability under normal conditions.

19. (A) A sharp surge in respiration rate and autocatalytic ethylene production
Climacteric fruits are distinguished by a dramatic increase in both respiration and ethylene synthesis at the onset of ripening. This ethylene production is autocatalytic, meaning the presence of the hormone triggers further synthesis to coordinate the ripening process across the entire fruit. These fruits, such as apples and bananas, can continue to ripen normally even after being detached from the plant.

20. (D) P-3, Q-4, R-1, S-2
1-methylcyclopropene competitively blocks ethylene receptors, while aminoethoxyvinylglycine inhibits the enzyme responsible for ACC synthesis. Controlled atmosphere storage extends shelf life by manipulating oxygen and carbon dioxide levels to slow down respiration rates. Additionally, polyamines serve as anti-senescence agents by stabilizing cellular membranes and maintaining overall tissue integrity during the post-harvest storage period. This combination of techniques optimizes produce quality.

21. (B) Increased activity of polygalacturonase and cellulase enzymes
The characteristic softening of fruit during ripening is a result of the systematic degradation of the primary cell wall and middle lamella. Enzymes such as polygalacturonase and cellulase break down complex pectin and cellulose polymers into smaller, soluble fragments. This biochemical dismantling reduces the structural integrity and firmness of the fruit tissue, leading to the melting texture preferred by many consumers.

22. (C) Acts as a mucosal adjuvant that binds to intestinal receptors
The cholera toxin B subunit is a non-toxic component frequently used in the development of edible vaccines because of its powerful immunogenic properties. It functions as a mucosal adjuvant by binding specifically to GM1 ganglioside receptors on the surface of intestinal epithelial cells. This binding facilitates the uptake of the vaccine antigen, triggering a robust immune response within the gut.

23. (D) Chloroplast
The chloroplast is typically the first organelle to exhibit visible structural changes during the initiation of leaf senescence. As the dismantling process begins, the thylakoid membranes break down and the chlorophyll molecules are degraded, leading to the characteristic yellowing of the tissue. This early degradation is essential for the rapid remobilization of nitrogen and other minerals stored in photosynthetic proteins.

24. (A) Progressive senescence - Agave and bamboo
Progressive senescence describes a sequential pattern of leaf death moving from the base to the top of a plant. Agave and bamboo are actually examples of monocarpic plants, which undergo a massive, synchronous senescence of the entire organism after a single reproductive event. Deciduous and top senescence correctly describe the patterns observed in maple trees and perennial geophytes respectively.

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25. (B) Phloem
During monocarpic senescence, the breakdown of cellular components in the leaves produces a variety of mobile nutrients, including amino acids and minerals. These products are actively loaded into the phloem for long-distance transport to the developing seeds and fruits. The phloem serves as the primary conduit for redistributing these essential resources, ensuring that the plant's reproductive effort is maximized before death.

26. (B) Ethylene
Ethylene is a potent gaseous hormone that can trigger and accelerate the ripening and senescence of many horticultural crops even at very low concentrations. In controlled atmosphere storage, it is critical to exclude or remove ethylene to prevent premature softening and quality loss in apples. Maintaining an ethylene-free environment effectively delays the climacteric burst and extends the possible storage duration significantly.

27. (A) ERS1 - Endoplasmic reticulum membrane
Ethylene receptors in plants, such as ETR1 and ERS1, are primarily localized to the membrane of the endoplasmic reticulum. These receptors

9. (B) Actively suppress the downstream ethylene response pathway
In the absence of ethylene, the CTR1 protein acts as a negative regulator by actively suppressing the downstream response pathway. It functions as a serine/threonine kinase that interacts with ethylene receptors to prevent the activation of signaling components like EIN2. This constitutive suppression ensures that ethylene-responsive genes remain inactive until the hormone is present to inhibit CTR1 and initiate signaling.

10. (C) A is true but R is false.
Ethylene receptors like ETR1 function as negative regulators, meaning they actively inhibit the signaling pathway when the hormone is absent. Binding of ethylene actually inactivates the receptor's kinase activity, which relieves the suppression of downstream components. This allows the signal to proceed through EIN2 and EIN3 to activate gene expression. The assertion is correct, but the reason provided is inaccurate.

11. (A) Pheophorbide a oxygenase (PAO)
During the dismantling of chloroplasts, the porphyrin ring of pheophorbide a must be opened to eliminate its phototoxicity. This critical reaction is catalyzed by the enzyme pheophorbide a oxygenase, leading to the formation of red chlorophyll catabolite. This step is essential for the transition from green to colorless catabolites, preventing light-induced damage while nutrients are remobilized from the leaf.

12. (C) Ethylene
Ethylene is the primary gaseous hormone recognized for its role in accelerating the senescence and abscission of petals in many cut flower species. It triggers a cascade of biochemical events, including the induction of hydrolytic enzymes that break down cell walls and proteins. Managing ethylene levels or sensitivity is therefore a fundamental strategy for extending the vase life of flowers.

13. (D) NAC and WRKY
The execution phase of leaf senescence is controlled by a complex network of transcription factors that regulate the expression of senescence-associated genes. Members of the NAC and WRKY families are particularly prominent, as they are strongly upregulated to coordinate cellular dismantling and nutrient remobilization. These factors integrate signals from plant age, hormonal levels, and environmental stresses to initiate death.

14. (C) Cysteine protease
Senescence-Associated Gene 12 is a well-known molecular marker that encodes a specific cysteine protease. This enzyme is typically localized within senescence-associated vacuoles, where it plays a vital role in the degradation of proteins during the final stages of leaf aging. Its expression is strictly regulated by the developmental age of the tissue rather than by external environmental stress factors.

15. (B) DNA laddering due to internucleosomal cleavage
Plant programmed cell death often shares morphological and biochemical features with animal apoptosis, including the characteristic cleavage of nuclear DNA. This internucleosomal fragmentation, known as DNA laddering, is caused by the activation of specific endonucleases during the execution phase. Such controlled dismantling of the genome ensures that the cell death process is orderly and does not trigger unwanted inflammatory responses.

16. (D) Maximum dry weight is reached and nutrient transport to the seed ceases
Physiological maturity in crop seeds marks the point at which the embryo has completed its development and the seed has accumulated its maximum amount of dry matter. At this stage, the funiculus or vascular connection often detaches, ending the flow of nutrients from the parent plant. While the moisture content remains high, the seed is biologically prepared for eventual dispersal.

17. (A) Increased lignification and cell wall thickening
The loss of quality in asparagus spears during post-harvest storage is primarily due to the rapid toughening of the tissue. This undesirable change results from the continued synthesis and deposition of lignin within the cell walls, particularly near the base of the spear. This lignification process increases the mechanical strength of the fibers, making the vegetable woody and unpalatable.

18. (C) High temperature and high relative humidity
Accelerated aging tests are used to evaluate the vigor and storage potential of seed lots by

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down the fruit's respiration and transpiration rates. These coatings, often made from waxes or resins, help maintain firmness and reduce weight loss post-harvest.

37. (B) It allows for targeted downregulation of specific enzymes without altering other traits
Antisense RNA technology provides a precise method for silencing specific genes involved in ripening and senescence. Unlike traditional breeding, which can introduce undesirable traits through genetic linkage, this molecular approach allows for the modification of a single enzyme's activity while keeping the rest of the plant's genome intact. This specificity is crucial for maintaining the flavor and nutritional quality of crops.

38. (C) Accelerated lipid peroxidation and enzymatic hydrolysis of stored reserves
Seeds stored under conditions of high relative humidity deteriorate rapidly because the increased moisture stimulates metabolic activity and oxidative reactions. Lipid peroxidation occurs as free radicals attack the unsaturated fatty acids in cellular membranes, leading to structural damage. Simultaneously, hydrolytic enzymes begin to break down stored proteins and carbohydrates, depleting the energy reserves necessary for successful germination and early seedling growth.

39. (D) Grape
Grapes are classic examples of non-climacteric fruits, as they do not show a surge in respiration or ethylene production during the ripening phase. Their maturation process occurs slowly while they are still attached to the vine, and they do not ripen further once harvested. In contrast, apples, bananas, and tomatoes are climacteric and exhibit a characteristic peak in metabolic activity.

40. (A) Ethylene binds receptor → CTR1 is inactivated → EIN2 is cleaved → EIN3 promotes transcription
The ethylene signaling pathway is initiated when the hormone binds to its receptors, leading to the inactivation of the negative regulator CTR1. This inactivation allows the C-terminal end of the EIN2 protein to be cleaved and transported into the nucleus. Once inside, this fragment stabilizes the EIN3 transcription factors, which subsequently activate the expression of various ethylene-responsive target genes.

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41. (B) CA uses precise mechanical monitoring, while MA relies on film and respiration
Controlled atmosphere storage involves the active and precise mechanical adjustment of gas concentrations within a sealed storage facility. In contrast, modified atmosphere storage is a more passive process where the gas composition is altered by the natural respiration of the produce within a semi-permeable film. While both methods aim to reduce oxygen and increase carbon dioxide, CA offers greater stability.

42. (B) Calcium
Bitter pit is a common physiological disorder in apples that appears as small, sunken, dark spots on the skin and flesh. It is caused by a localized deficiency of calcium in the fruit tissue, often exacerbated by environmental stress or improper nutrient management. Calcium is essential for maintaining the structural integrity of cell walls and membranes, and its lack leads to collapse.

43. (A) It irreversibly binds to the ethylene receptor, blocking subsequent signaling
1-methylcyclopropene is a gaseous compound that effectively delays the ripening of climacteric fruits by blocking ethylene perception. It works by binding irreversibly to the ethylene receptors, preventing the hormone from initiating the signal transduction pathway. Because the fruit cannot "sense" the ethylene, the biochemical processes associated with ripening and senescence, such as softening and color changes, are significantly slowed down.

44. (C) Elimination of the need for cold chain logistics for vaccine distribution
One of the most significant advantages of edible vaccines is their potential for easy distribution in developing regions. Because the vaccine antigens are bio-encapsulated within the plant's cells, they are more stable at ambient temperatures than traditional liquid vaccines. This stability eliminates the requirement for expensive and complex cold chain infrastructure, making life-saving immunizations more accessible to remote populations.

45. (D) Malondialdehyde (MDA)
Malondialdehyde is a major end-product of the oxidative degradation of polyunsaturated

fatty acids in cellular membranes. During plant senescence, the accumulation of reactive oxygen species leads to increased lipid peroxidation, and the level of MDA is frequently measured as a reliable biochemical marker of this damage. Monitoring MDA concentrations helps researchers quantify the extent of membrane disruption and overall cellular aging.

46. (C) Flower disconnection from sources combined with high respiration consumption
Once cut, flowers are physically separated from the parent plant, which serves as the primary source of sugars produced through photosynthesis. However, the metabolic demand of the flower remains high as it continues to respire and undergo senescence. This imbalance leads to the rapid depletion of internal carbohydrate reserves, resulting in a loss of turgor and the eventual wilting of petals.

47. (B) It acts as a biocide and inhibits ethylene action at the receptor level
Silver thiosulfate is widely used in the floriculture industry to extend the vase life of ethylene-sensitive flowers. The silver ions in the complex act by blocking the ethylene receptors, thereby preventing the hormone from triggering the senescence process. Additionally, the compound provides some antimicrobial benefits, helping to maintain the cleanliness of the vase water and reducing vascular occlusion in stems.

48. (D) Physiological maturity
In corn development, the appearance of a dark or black layer in the hilum region at the base of the kernel is a key morphological indicator. This "black layer" signals that the seed has reached physiological maturity, meaning it has attained its maximum dry weight and nutrient transport from the cob has ceased. This marker is commonly used by farmers to determine harvest timing.

49. (A) The central vacuole
The rupture of the tonoplast, or the membrane of the central vacuole, is a critical and irreversible step in plant programmed cell death. This collapse releases a variety of hydrolytic enzymes into the cytoplasm, leading to the rapid autolysis and dismantling of the cell's internal components. This final execution step ensures that the cell's contents are broken down for potential nutrient recycling.

50. (C) II and IV
During fruit ripening, starch is typically hydrolyzed into sugars and chlorophyll is degraded, but organic acid concentrations usually decrease, leading to a reduction in titratable acidity. Furthermore, the production of volatile organic compounds actually increases significantly to create the characteristic aromas that attract seed dispersers. Therefore, the statements concerning increasing acidity and decreasing volatile production are scientifically incorrect.

51. (A) Esters, alcohols, and aldehydes from fatty acids and amino acids
The characteristic aroma of a ripe fruit is the result of a complex blend of volatile organic compounds synthesized during the final stages of maturation. These compounds, including various esters, alcohols, and aldehydes, are derived from the metabolic breakdown of fatty acids and amino acids. These aromatic signals are essential for attracting animals that assist in the dispersal of the mature seeds.

52. (D) Degrade specific mRNA transcripts to silence the expression of ripening genes
RNA interference is a powerful molecular tool used to silence specific genes by targeting their messenger RNA for degradation. By introducing double-stranded RNA sequences that match the target ripening gene, researchers can prevent the translation of enzymes such as polygalacturonase or ACC oxidase. This downregulation effectively delays the ripening process and extends the shelf life of the modified horticultural crops.

53. (B) Cytokinin
Cytokinins are widely recognized as the primary hormones that function antagonistically to ethylene and abscisic acid in the regulation of leaf senescence. High levels of cytokinin promote nutrient retention and maintain chlorophyll content, effectively delaying the aging process. The onset of senescence is often triggered by a decrease in the ratio of cytokinin to these senescence-promoting hormones within the leaf tissue.

54. (C) Proteases and peptidases
The degradation of proteins into free amino acids is a fundamental process during the post-harvest storage of many field crops. This breakdown is predominantly catalyzed by various proteases

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and peptidases that are activated as the tissue undergoes senescence or responds to stress. These enzymes dismantle functional proteins, allowing for the remobilization of nitrogen but often leading to a loss of nutritional quality.

55. (D) Non-climacteric fruits lack an autocatalytic System 2 ethylene production pathway.
Non-climacteric fruits differ from climacteric ones because they do not exhibit a surge in ethylene production or respiration during ripening. Specifically, they lack the "System 2" pathway, which is the autocatalytic mechanism where ethylene triggers its own massive synthesis. While they may still produce small amounts of ethylene, it does not lead to the coordinated ripening burst seen in climacteric species.

56. (A) Top senescence
Top senescence is a specific pattern observed in many herbaceous perennial plants where the entire above-ground portion dies back at the end of the growing season. While the aerial stems and leaves undergo programmed senescence and death, the underground structures like rhizomes, bulbs, or tubers remain viable. This strategy allows the plant to survive harsh winter conditions and regrow during the following spring.

57. (B) Increases equilibrium moisture content, stimulating fungal and metabolic activity
High relative humidity in storage environments is detrimental to seed longevity because it raises the seed's equilibrium moisture content. This increased moisture stimulates higher rates of respiration and metabolic activity, leading to the rapid depletion of stored energy reserves. Furthermore, moist conditions provide an ideal environment for the growth of storage fungi, which further accelerates the deterioration and death of seeds.

58. (B) They stimulate the production of Secretory IgA upon encountering gut lymphoid tissue
Edible vaccines are designed to trigger mucosal immunity by interacting with the lymphoid tissue located in the lining of the gastrointestinal tract. Upon consumption, the vaccine antigens stimulate the production of secretory IgA antibodies, which provide the first line of defense against pathogens entering through mucosal surfaces. This type of immunity is particularly effective at preventing infections in the gut and respiratory system.

59. (A) Red chlorophyll catabolite (RCC)
In the pathway of chlorophyll degradation, the opening of the pheophorbide a ring leads to the formation of red chlorophyll catabolite. This intermediate is then further reduced to produce primary fluorescent chlorophyll catabolites. These steps are part of a highly regulated process that safely dismantles the light-harvesting complex, preventing the accumulation of toxic photo-sensitizing molecules while the leaf tissue undergoes senescence.

60. (C) A is true but R is false.
Polyamines are known to delay senescence in plant tissues because they stabilize cellular membranes and compete for the same precursor used in ethylene biosynthesis. However, they do not function by mimicking ethylene or binding to the ETR1 receptor. In fact, their action is generally antagonistic to ethylene, meaning the assertion regarding their benefit is correct, but the reason describing their mechanism is entirely false.

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61. (D) ATP
The initial step of the Yang cycle involves the activation of methionine to S-adenosylmethionine. This reaction is catalyzed by the enzyme SAM synthetase and requires a constant supply of ATP to provide the necessary energy. Without sufficient ATP, the production of SAM would be halted, which would subsequently limit the synthesis of ethylene and other downstream metabolites involved in plant growth and stress responses.

62. (C) Chilling injury including pitting, discoloration, and failure to ripen
Tropical and subtropical fruits like mangoes and papayas are highly susceptible to chilling injury when stored at temperatures below approximately ten degrees Celsius. Storing them at four degrees Celsius causes a disruption of cellular membranes and metabolic pathways. The symptoms of this injury include surface pitting, internal browning, and a permanent failure to ripen normally, significantly reducing the fruit's marketability and flavor.

63. (B) ERF (Ethylene Response Factor)
Ethylene Response Factors are a large family of transcription factors that act at the final stage of the hormone's signaling pathway. They are directly regulated by master switches like EIN3 and are responsible for activating the expression of secondary ethylene response genes. These genes encode various enzymes, such as cellulase and polygalacturonase, which execute the physical and biochemical changes associated with ripening.

64. (D) The potential for transgene flow to wild relatives or other food crops
One of the primary biosafety concerns regarding transgenic crops for edible vaccines is the risk of environmental contamination. This includes the possibility of pollen-mediated gene flow to wild relatives or the accidental mixing of vaccine-producing plants with conventional food crops. Such events could lead to the unintended exposure of humans or wildlife to the vaccine antigens, raising significant regulatory and health challenges.

65. (A) The abrupt rise in respiration accompanying the ripening of pome fruits
The term "climacteric" was first introduced in the early twentieth century to describe the characteristic sharp increase in respiration observed during the ripening of apples and pears. This respiratory burst is a defining physiological feature that marks the transition from growth to senescence in many fleshy fruits. It is closely associated with a simultaneous surge in ethylene production, which coordinates the ripening process.

66. (C) Create a protective suberized scar tissue prior to the organ shedding event
The formation of an abscission zone is a vital developmental process that allows plants to shed leaves, fruits, and flowers in a controlled manner. Before the organ is detached, the plant develops a protective layer of cells infused with suberin and lignin on the stem side. This "scar tissue" seals the vascular connections and protects the internal tissues from water loss and pathogen entry.

67. (A) Autolysis mediated by the rupture of the central vacuole
The maturation of xylem tracheary elements involves a specialized form of programmed cell death where the cell's protoplast is completely removed. This process is driven by autolysis, which begins with the rupture of the central vacuole. The released hydrolytic enzymes digest the cell's internal organelles and cytoplasm, leaving behind a hollowed-out cell wall that functions as a conduit for long-distance water transport.

68. (D) System 1 is vegetative and auto-inhibitory; System 2 is autocatalytic
Plants utilize two distinct systems for ethylene production during their life cycle. System 1 operates at low levels in vegetative tissues and is typically auto-inhibitory, meaning that ethylene suppresses its own synthesis. In contrast, System 2 is activated during the ripening of climacteric fruits and the senescence of certain flowers. This system is autocatalytic, where the presence of ethylene triggers a massive surge.

69. (B) Reducing sugars (glucose and fructose)
Storing potatoes at low temperatures leads to a phenomenon known as "cold sweetening," where starch is enzymatically converted into reducing sugars like glucose and fructose. While this may seem harmless, these sugars react with amino acids during high-temperature cooking, such as frying, to produce dark colors and bitter flavors. This reaction, known as the Maillard reaction, also leads to the formation of acrylamide.

70. (C) P-2, Q-4, R-1, S-3
Different crops rely on specific indices to determine maturity. Citrus fruits are judged by their juice content and sugar-to-acid ratio, while walnuts and macadamias are harvested based on shell hardness. Maize reaches physiological maturity when a black layer forms at the kernel base, and sweet corn harvest timing is often determined by the thermal time accumulated since the silking stage.

71. (D) MADS-box transcription factor required for ripening activation
The "rin" mutant of tomato is a well-studied genetic variant that fails to undergo a normal respiratory climacteric or ethylene surge. This phenotype is caused by a mutation in a gene encoding a MADS-box transcription factor, which serves as a master regulator of the ripening process. Without functional RIN protein, the fruit cannot activate the downstream genes required for softening, color change, and aroma.

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72. (A) Photoperiod manipulation
Controlled atmosphere storage relies on the precise management of temperature and the concentrations of oxygen and carbon dioxide to extend the shelf life of produce. These factors directly influence the respiration rate and ethylene sensitivity of the fruit. However, photoperiod manipulation is not relevant in this context because the fruit is stored in total darkness, and light does not play a role in this post-harvest strategy.

73. (B) Lipoxygenase - Synthesizes hemicellulose cross-links
Lipoxygenase is an enzyme primarily involved in the oxidative degradation of lipids in cellular membranes rather than the synthesis of cell wall components. During fruit ripening, its activity contributes to membrane disruption and the production of volatile aroma compounds. In contrast, enzymes like polygalacturonase, cellulase, and pectin methylesterase are directly responsible for the systematic breakdown and modification of the various cell wall polysaccharides.

74. (B) Xylem water potential depletion caused by bacterial plugging
The "bent neck" disorder in cut roses is a common symptom of water stress occurring in the pedicel just below the flower head. This is typically caused by the physical blockage of xylem vessels by bacterial colonies and their secretions, which prevents adequate water transport. As the water potential in the pedicel drops, the tissue loses turgor and can no longer support the weight.

75. (A) The ACS mutant ripens with exogenous ethylene; the ETR1 mutant does not
A mutant lacking the ACC synthase enzyme cannot produce its own ethylene but still possesses the ability to sense the hormone. Therefore, it will ripen if exposed to external ethylene gas. In contrast, a mutant with a non-functional ETR1 receptor is "blind" to ethylene and cannot respond to the hormone at all, regardless of whether it is produced internally or applied externally.

76. (C) Glutamine and asparagine
During leaf senescence, proteins are broken down into amino acids, which are then converted into specific forms for long-distance transport through the phloem. Glutamine and asparagine are the primary transport molecules because they have a high nitrogen-to-carbon ratio, making them efficient carriers. These amides are moved from the aging leaves to developing seeds or storage organs where the nitrogen is reused.

77. (D) Cobalt ions ($Co^{\{2+\}}$)
Cobalt ions are known to act as specific inhibitors of the enzyme ACC oxidase, which catalyzes the final step of ethylene biosynthesis. By preventing the conversion of ACC to ethylene, cobalt can delay the onset of senescence and ripening in various plant tissues. While other chemicals like AVG and AOA inhibit earlier steps in the pathway, cobalt is unique in targeting the terminal reaction.

78. (C) Lipoxygenase (LOX)
Lipoxygenase is a key enzyme that initiates the oxidation of polyunsaturated fatty acids in the lipid bilayer of cellular membranes. Its activity leads to the production of lipid hydroperoxides and free radicals, which cause significant structural damage to the cell. During senescence, increased LOX activity is directly correlated with a rise in membrane permeability and the eventual loss of cellular compartmentalization and function.

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79. (B) Removing the flowers or young pods before they develop
Monocarpic senescence in plants like soybeans is triggered by the development of seeds and fruits, which act as dominant sinks for nutrients. Experimentally removing the flowers or young pods prevents this massive remobilization and can significantly delay the senescence of the vegetative organs. This demonstrates that the reproductive organs play a crucial role in signaling the initiation of the whole-plant death program.

80. (D) I, III and IV
Seed deterioration is a complex process characterized by the loss of membrane integrity and the depletion of antioxidant defenses. During dry storage, non-enzymatic browning through Maillard reactions also contributes to the gradual decline in seed quality. However, high moisture does not extend viability; instead, it accelerates death. Furthermore, most orthodox seeds can safely tolerate sub-zero temperatures if they are first properly dried.

99. (A) Ethylene perception is mediated by receptors whose mutation blocks ripening
The "Never-ripe" tomato mutant was instrumental in demonstrating the essential role of ethylene perception in the ripening process. Because the mutant has a defect in one of its ethylene receptors, it cannot respond to the hormone, even though it produces ethylene normally. This failure to sense the signal prevents the fruit from ripening, proving that the hormonal signal must be perceived to initiate maturation.

100. (C) A is true but R is false.
1-methylcyclopropene is a highly effective tool in post-harvest management because it blocks the perception of ethylene at the receptor level. While the compound successfully delays ripening in climacteric fruits, it does not function by inhibiting the ACC synthase enzyme. Instead, it prevents the fruit from responding to both endogenous and exogenous ethylene by irreversibly binding to its specific protein receptors.

101. (B) Attainment of a root diameter and color standard required by the market
Root crops like carrots and radishes do not have a single biological stage of physiological maturity. Instead, they are harvested based on commercial standards such as size, weight, and color. These standards ensure that the vegetable meets consumer expectations for appearance and flavor. Because these crops can continue to grow if left in the ground, harvest timing is determined by the specific market requirements.

102. (B) Modified Atmosphere Packaging (MAP)
Modified atmosphere packaging utilizes the selective permeability of plastic films to regulate the exchange of gases between the produce and the outside environment. The film allows carbon dioxide to escape and oxygen to enter at different rates. Combined with the natural respiration of the fruit or vegetable, this creates an internal atmosphere with reduced oxygen and increased carbon dioxide, effectively slowing down senescence.

103. (A) Tolerate extreme desiccation and freezing without losing viability
Orthodox seeds are defined by their remarkable ability to survive significant drying and exposure to freezing temperatures. Most common agricultural seeds, such as wheat, corn, and beans, fall into this category. This tolerance allows them to be stored for very long periods in gene banks, provided they are kept at low moisture levels and sub-zero temperatures to minimize their metabolic activity.

104. (D) Are susceptible to desiccation injury and cannot be dried to low moisture
Recalcitrant seeds differ from orthodox seeds because they cannot survive being dried below a relatively high moisture threshold. This sensitivity to desiccation means they must be stored in a moist environment, which also encourages metabolic activity and fungal growth. Consequently, these seeds lose their viability very quickly and cannot be preserved using standard long-term cold storage techniques in germplasm banks.

105. (A) Temperature gradients causing convection currents that carry moisture
In large grain silos, temperature differences between the bulk of the grain and the outside walls can create air convection currents. These currents carry moisture from warmer regions and deposit it in cooler areas, leading to localized "hot spots" with high moisture. This moisture migration encourages the growth of mold and insects, even if the grain was initially stored at a safe average moisture level.

106. (C) Ethylene perception triggers up-regulation of ACS and ACO transcription
Autocatalytic ethylene production is a self-reinforcing loop that occurs during the ripening of climacteric fruits. When the fruit senses a small amount of ethylene, it activates the transcription of the genes responsible for its own biosynthesis, such as ACS and ACO. This leads to a massive surge in hormone levels, ensuring that all tissues within the fruit undergo the ripening process synchronously.

107. (A) Xyloglucan endotransglycosylase (XET) and expansins
The degradation of hemicelluloses during fruit softening is a complex process involving the coordinated action of several enzymes. Xyloglucan endotransglycosylase cleaves and reconnects hemicellulose chains, while expansins work to loosen the non-covalent bonds between these chains and cellulose microfibrils. This synergy increases the accessibility of the cell wall

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90. (B) III, II, I, IV
Commercial post-harvest handling of cut flowers begins with harvesting at the correct stage of maturity. The flowers are then immediately pre-cooled to remove field heat and slow down their metabolism. This is followed by hydration in acidic water containing biocides to prevent vascular blockage. Finally, anti-ethylene treatments are applied to protect the flowers from the effects of the hormone during storage.

91. (A) Auto-regulating cytokinin production to delay senescence after development
The promoter of the SAG12 gene is highly valuable because its expression is specific to the late stages of leaf aging. By linking this promoter to a gene for cytokinin synthesis, researchers can create a self-regulating system. When senescence begins, the promoter activates the synthesis of cytokinin, which then acts to delay the senescence process itself, resulting in plants with an extended leaf life.

92. (C) The construct synthesizes IPT at the onset of senescence to produce cytokinins
Transgenic plants with the SAG12-IPT construct stay green longer because they utilize a senescence-specific promoter to drive the expression of the isopentenyltransferase gene. This enzyme is responsible for the rate-limiting step in cytokinin biosynthesis. As the leaf begins to age, the promoter activates IPT synthesis, increasing local cytokinin levels and effectively inhibiting the breakdown of chlorophyll and other proteins associated with senescence.

93. (D) A rapid phase transition of membrane lipids from fluid to a solid gel state
Chilling injury in sensitive plants like bananas is fundamentally caused by the physical behavior of membrane lipids at low temperatures. As the temperature drops below a certain threshold, the lipid bilayer transitions from a flexible, fluid state to a rigid, gel-like state. This transition disrupts the function of membrane proteins and increases permeability, leading to metabolic imbalances and the characteristic symptoms of injury.

94. (C) Controlled Atmosphere (CA) storage
Controlled atmosphere storage is a sophisticated post-harvest technology where the concentrations of oxygen and carbon dioxide are precisely maintained. Typically, oxygen is reduced to very low levels and carbon dioxide is slightly increased compared to normal air. This environment significantly reduces the respiration rate and ethylene sensitivity of the stored produce, thereby extending its shelf life while maintaining its nutritional and visual quality.

95. (B) NAC
Members of the NAC transcription factor family are central regulators of the leaf senescence process. They integrate various developmental and environmental signals to initiate the expression of senescence-associated genes. Many NAC factors specifically promote abscisic acid signaling and other pathways that lead to cellular dismantling. Their activity is crucial for coordinating the orderly death of the leaf and the efficient remobilization of its nutrients.

96. (D) Unmasking of pre-existing carotenoids through chlorophyll degradation
The characteristic color change in many ripening fruits is not always due to the new synthesis of pigments. In many cases, the yellow and orange carotenoids are already present in the tissue but are hidden by the high concentration of green chlorophyll. As chlorophyll is enzymatically degraded during the ripening process, these pre-existing pigments are unmasked, giving the fruit its final attractive color.

97. (A) Rapid autophagy and nuclease up-regulation causing collapse within a day
Ephemeral flowers like the morning glory are characterized by a very short lifespan, often wilting within a single day. This rapid senescence is driven by the activation of autophagy and the upregulation of nucleases that quickly dismantle the cellular components of the petals. This highly efficient programmed cell death allows the plant to recycle resources from the flower almost as soon as pollination ends.

98. (C) Generation of ATP for the synthesis of ripening-related enzymes and pigments
The sharp increase in respiration known as the climacteric peak provides the cellular energy necessary for the intensive metabolic work of ripening. This ATP is used to drive the de novo synthesis of various enzymes, such as those involved in cell wall softening and the production of new pigments and volatile aroma compounds. Without this metabolic surge, the fruit could not successfully complete its transformation.

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an internal block to germination, quiescence is easily overcome once the necessary conditions are met. It allows seeds to wait for the ideal time to begin growth in the field.

117. (C) Recycled back to methionine via the methylthioadenosine salvage pathway
The Yang cycle is a highly efficient metabolic pathway that allows plants to produce ethylene without depleting their supply of methionine. During the synthesis of ACC, the sulfur atom from methionine is released as 5-methylthioadenosine. This compound is then recycled through a series of reactions back into methionine, ensuring that the sulfur remains available for continued ethylene production and other essential cellular processes.

118. (A) Silver ions block the ethylene receptor, preventing signal transduction
Silver ions are widely used in research and the floral industry because they are powerful inhibitors of ethylene action. They function by binding to the ethylene receptors in place of the hormone, effectively blocking the signal from being transmitted through the rest of the pathway. Because the plant cannot perceive the ethylene, the biological processes it normally triggers, such as ripening or wilting, are inhibited.

119. (A) Begins in older basal leaves and moves upward to the flag leaf
In cereal crops like wheat, senescence follows a progressive and sequential pattern. The process begins in the oldest leaves at the base of the plant and gradually moves upward as the plant matures. The flag leaf, which is the youngest and most important for grain filling, is typically the last to undergo senescence. This pattern ensures that nutrients are efficiently remobilized toward the developing seeds.

120. (B) I and III
Edible vaccines work by expressing foreign antigens within the edible tissues of transgenic plants, which are then consumed to trigger an immune response. They do not require the injection of purified antigens into the plant. Furthermore, while they offer many advantages, they do not automatically eliminate the risk of transgene escape to wild relatives, which remains a significant biosafety concern in agricultural biotechnology.

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121. (B) Can be consumed raw to prevent heat denaturation of the vaccine protein
The ideal plant for an edible vaccine is one that can be eaten without cooking, as high heat can easily destroy the structure and effectiveness of the vaccine protein. Crops such as bananas, tomatoes, and certain leafy greens are preferred candidates because they are commonly consumed raw. This preservation of the antigen's structural integrity is essential for ensuring that it can successfully trigger an immune response.

122. (B) Lower respiration rates and delay the onset of the climacteric peak
Managing the cold chain is the most important strategy for extending the shelf life of climacteric fruits. Low temperatures directly reduce the activity of enzymes involved in respiration and ethylene synthesis. By slowing down these metabolic processes, the onset of the climacteric burst and the subsequent ripening events are delayed, allowing the fruit to be transported and stored for much longer periods.

123. (A) Tracheid cavitation caused by cutting stems in the air rather than underwater
When flower stems are cut in the air, the tension in the xylem can draw air bubbles into the vessels, a process known as cavitation. These air embolisms act as physical blocks that prevent the upward movement of water to the flower head. Cutting the stems underwater prevents air from entering, maintaining a continuous water column and helping to ensure that the flower remains hydrated.

124. (B) The shedding of organs following cell wall dissolution in a separation zone
Abscission is a highly controlled developmental process by which plants shed entire organs, such as leaves, fruits, or flowers. It occurs at a specific location called the abscission zone, where the middle lamella between cell layers is enzymatically dissolved. This separation allows the organ to detach cleanly from the plant body without causing extensive damage to the remaining tissues on the parent plant.

125. (B) The oxidative pentose phosphate pathway and glycolysis
During the post-harvest storage of root vegetables, internal carbohydrate reserves are gradually consumed to provide energy for ongoing cellular metabolism. This process

structure to other hydrolytic enzymes, ultimately leading to the softening of the fruit.

108. (D) Citric acid
Citric acid is a common ingredient in commercial floral preservatives because it serves several important functions. By lowering the pH of the vase water, it inhibits the growth of bacteria that could clog the xylem vessels of the stems. Additionally, the acidic environment improves the solubility and uptake of water and nutrients, helping to maintain petal turgor and extend flower life.

109. (B) Chemically oxidizes and removes free ethylene gas from the storage atmosphere
Potassium permanganate is a powerful oxidizing agent used in the storage and transport of horticultural produce to control ethylene levels. It reacts chemically with the ethylene gas in the air, converting it into carbon dioxide and water. By removing the hormone from the storage environment, it prevents the premature ripening and senescence of ethylene-sensitive crops, thereby extending their marketable shelf life significantly.

110. (C) P-3, Q-4, R-2, S-1
Molecular techniques have been used to target various stages of ripening and senescence. Antisense technology against polygalacturonase reduces cell wall softening, while overexpressing SAM hydrolase depletes the precursor needed for ethylene synthesis. RNA interference can be used to block the final step of ethylene production by targeting ACC oxidase, and the SAG12-IPT construct allows for the auto-regulated production of cytokinin to delay leaf aging.

111. (A) Tonoplast rupture and release of vacuolar hydrolases into the cytosol
The rupture of the tonoplast membrane is a definitive marker of the irreversible execution phase of plant programmed cell death. When the central vacuole collapses, it releases a high concentration of hydrolytic enzymes that were previously sequestered. These enzymes immediately begin to digest the cellular organelles and cytoplasm, leading to the rapid autolysis of the cell. This process is fundamentally different from reversible stress responses.

112. (B) Application of exogenous cytokinin
Cytokinins are potent inhibitors of the senescence process and act to maintain cellular integrity in aging tissues. When exogenous cytokinin is applied to a leaf, it suppresses the expression of senescence-associated genes, which are normally upregulated as the tissue gets older. By downregulating these genes, the hormone prevents the activation of the pathways responsible for chlorophyll degradation and protein breakdown.

113. (B) Reactive oxygen species (ROS) like H_2O_2
The accumulation of reactive oxygen species is a hallmark of both physiological aging and programmed senescence in plants. These highly reactive molecules cause extensive damage to DNA, proteins, and lipids through oxidative stress. During senescence, the plant's antioxidant defense systems are often overwhelmed, leading to the breakdown of cellular membranes and the loss of compartmentalization, which eventually results in the death of the cell.

114. (A) Sink removal causes sugar buildup in leaves, suppressing the trigger
In many plant species, the accumulation of sugars in the leaves can act as a signal to delay the onset of senescence. When flowers or developing fruits are removed, the "sinks" for the plant's carbohydrates are gone, leading to a buildup of sugars in the source leaves. This high sugar concentration suppresses the expression of senescence-associated genes, effectively extending the lifespan of the foliage.

115. (D) Rapid loss of marketable quality and a significant shortening of shelf life
High respiration rates in harvested vegetables are indicative of intense metabolic activity, which consumes stored energy reserves like sugars and starch. This rapid consumption of resources leads to a faster decline in nutritional value, flavor, and texture. Furthermore, respiration generates heat, which can further accelerate decay and the growth of pathogens, ultimately reducing the time the produce remains marketable.

116. (A) Quiescence
Quiescence is a physiological state where a viable, non-dormant seed fails to germinate simply because the external environmental conditions, such as water, temperature, or oxygen, are not favorable. Unlike true dormancy, which is

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color changes, but they do not produce more ethylene as a result. This is in sharp contrast to climacteric fruits, where a small amount of ethylene triggers a massive surge.

135. (A) Supplying a low concentration of sucrose in the holding solution
Cut flowers often suffer from carbohydrate depletion because they are no longer receiving sugars from the parent plant. Adding a small amount of sucrose to the vase water provides a respirable energy source that the flower can use to maintain its cellular functions and turgor pressure. This supplemental sugar effectively delays the onset of senescence and helps to maintain the quality and lifespan of the petals.

136. (D) Hydrolysis and solubilization of pectic substances in the middle lamella
The transition from a firm to a soft texture during fruit ripening is primarily caused by the enzymatic breakdown of the middle lamella. Pectic substances, which normally act as the "glue" between cells, are hydrolyzed and become more soluble. As the bonds between cells are weakened, the tissue loses its structural integrity, resulting in the characteristic softening and eventual melting texture that many consumers associate with ripeness.

137. (B) Fruit shifts to anaerobic respiration, producing off-flavors
While low oxygen levels can significantly delay the ripening of fruit, dropping the concentration too low (typically below 1%) is dangerous. Under such extreme conditions, the fruit can no longer perform normal aerobic respiration and is forced to shift to anaerobic fermentation. This metabolic change leads to the accumulation of ethanol and acetaldehyde, which cause unpleasant off-flavors and can ultimately damage the fruit tissue.

138. (D) Intercellular sorbitol accumulation instead of fructose conversion
Water core is a physiological disorder of apples where the tissue around the core appears translucent and water-soaked. It is caused by the accumulation of sorbitol in the intercellular spaces. Normally, sorbitol is converted into fructose once it enters the fruit cells, but in affected fruits, this process is disrupted. The high concentration of sorbitol draws water into the spaces, leading to the characteristic water-soaked appearance.

139. (B) Compete for the SAM precursor shared with ethylene biosynthesis
Polyamines like spermine and spermidine are thought to delay senescence because they share a common metabolic precursor, S-adenosylmethionine, with the ethylene biosynthetic pathway. By competing for this limited resource, high levels of polyamines can effectively reduce the amount of SAM available for ethylene production. Additionally, polyamines are basic molecules that can help stabilize cellular membranes and proteins during the aging process.

140. (A) IV, II, III, I
The biosynthesis of ethylene follows a specific enzymatic sequence. First, methionine is activated by ATP to form S-adenosylmethionine (SAM). This intermediate is then converted into 1-aminocyclopropane-1-carboxylic acid (ACC) by the enzyme ACC synthase. Finally, ACC is oxidized by ACC oxidase to produce the final gaseous hormone, ethylene. Understanding this sequence is fundamental to controlling the ripening and senescence of horticultural crops.

141. (C) Specific to age-dependent leaf senescence and not induced by stress
The SAG12 gene is a highly specific marker because its expression is strictly linked to the developmental age of the leaf. Unlike many other senescence-associated genes, it is not induced by external stress factors like wounding, drought, or pathogen attack. This specificity makes its promoter an ideal tool for researchers who want to target and manipulate the natural, age-related senescence process without interfering with other responses.

142. (B) Maintains active photosynthesis longer to increase yield under stress
The "stay-green" trait is highly desirable in many crops because it allows the plant to maintain functional photosynthetic machinery for a longer period during grain filling. This is especially beneficial under conditions of environmental stress, such as terminal drought. By delaying the onset of leaf senescence, the plant can continue to produce carbohydrates and transport them to the developing seeds, resulting in higher overall yields.

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primarily occurs through glycolysis and the oxidative pentose phosphate pathway, which break down sugars into smaller molecules and release ATP. As these storage carbohydrates are depleted, the nutritional value and texture of the vegetable eventually begin to decline over time.

126. (A) Shriveled grains with reduced starch deposition
Exposure to high temperatures during the critical grain-filling stage accelerates the plant's development, leading to a phenomenon known as forced maturity. This heat stress shortens the time available for starch accumulation in the grain and can damage the enzymes involved in its synthesis. As a result, the grains fail to fill completely, appearing shriveled and having a significantly lower overall weight and yield.

127. (C) Salicylic acid
Salicylic acid is a key signaling molecule in the plant's defense response against pathogens. It is essential for the development of systemic acquired resistance, which provides long-lasting protection throughout the plant. In many cases, salicylic acid also promotes the development of localized necrotic lesions, known as the hypersensitive response, which limits the spread of infection by sacrificing the infected cells.

128. (A) Antisense strand binds to target mRNA to form dsRNA that is degraded
Antisense RNA technology works by introducing a genetic construct that produces an RNA strand complementary to the target gene's messenger RNA. When these two strands meet in the cell, they bind together to form a double-stranded RNA molecule. This abnormal structure is recognized by the cell's internal machinery and is targeted for immediate degradation, effectively preventing the synthesis of the target enzyme.

129. (A) It reduces the sensitivity of the abscission zone to ethylene
Auxins play a critical role in regulating the timing of organ shedding by acting as an antagonist to ethylene in the abscission zone. As long as there is a steady flow of auxin from the leaf or fruit, the cells in the separation layer remain insensitive to ethylene. Senescence and shedding occur when the auxin supply drops, allowing the tissue to respond to ethylene signals.

130. (B) I, III and IV
Programmed cell death is a fundamental part of normal plant development and is not just a response to disease. It is required for the formation of air-filled tissues in roots and for the hollowing out of xylem vessels for water transport. The process involves specific biochemical markers such as DNA fragmentation and the collapse of the central vacuole to ensure the dismantling is controlled.

131. (A) When the fruit is young and tender with soft, unformed seeds
For vegetables like zucchini and summer squash, commercial maturity is reached while the fruit is still biologically immature. Consumers prefer these vegetables when they are small and tender, with a high water content and soft seeds. If left to reach physiological maturity, the fruit would become large, tough, and fibrous, with hard seeds, making it unpalatable for most culinary uses.

132. (A) M cells (Microfold cells)
Edible vaccines are taken up by specialized cells in the lining of the gut known as M cells. These cells are located within the follicle-associated epithelium of Peyer's patches and are responsible for sampling antigens from the intestinal lumen. Once the M cells transport the vaccine antigen across the epithelial barrier, it is delivered to underlying immune cells to trigger a mucosal immune response.

133. (A) The 26S proteasome and various vacuolar proteases
The orderly dismantling of proteins during leaf senescence is a highly regulated process involving multiple degradation pathways. The 26S proteasome is responsible for breaking down specific tagged proteins in the cytoplasm, while a variety of proteases within the central vacuole and senescence-associated vacuoles digest the bulk of the leaf's proteins. This breakdown provides the amino acids that are then remobilized to other plant organs.

134. (B) Autocatalytic stimulation of its own ethylene production
A defining feature of non-climacteric fruits is that they lack the ability to undergo autocatalytic ethylene production. When these fruits, such as citrus or grapes, are treated with exogenous ethylene, they may show some responses like

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81. (A) Show delayed ripening and prolonged shelf life on the vine
Using antisense RNA to suppress the expression of ACC oxidase reduces the fruit's ability to produce ethylene. In cantaloupes, this transgenic modification leads to a significant delay in the ripening process, allowing the fruit to remain on the vine for a longer period without softening or spoiling. This technology provides a way to improve fruit quality and reduce post-harvest losses.

82. (C) A separation layer of small cells that respond to ethylene by secreting enzymes
The abscission zone is a specialized region at the base of the petiole or fruit stalk that consists of a layer of small, densely cytoplasmic cells. As the organ prepares to shed, these cells respond to ethylene by synthesizing and secreting hydrolytic enzymes like cellulase and pectinase. These enzymes dissolve the middle lamella, allowing the cells to pull apart and the organ to fall.

83. (A) Non-climacteric fruits
Citrus fruits are classified as non-climacteric because they do not exhibit a surge in respiration or ethylene production during their maturation. Their ripening is a gradual process that must be completed while the fruit is still attached to the tree. Because they lack the autocatalytic ethylene pathway, they do not show the characteristic respiratory burst that defines climacteric fruits like apples or tomatoes.

84. (D) Ambient relative humidity
The equilibrium moisture content of a seed is the specific moisture level it reaches when stored in an environment with a constant relative humidity. Because seeds are hygroscopic, they will either absorb or release moisture until their internal water potential matches that of the surrounding air. Therefore, the ambient relative humidity is the most critical environmental factor determining the moisture level and storage life.

85. (B) Chemically inhibiting the perception of ethylene at the receptor level
1-methylcyclopropene is a gaseous tool used to manage the post-harvest life of many crops by blocking ethylene perception. It functions by binding irreversibly to the ethylene receptors within the plant cells, preventing the hormone from triggering any biological responses. This method is highly effective because it stops the signaling pathway at its very beginning, regardless of how much ethylene is actually present.

86. (C) Alpha-farnesene oxidation into conjugated trienes that kill epidermal cells
Superficial scald is a common physiological disorder in cold-stored apples that manifests as a brown discoloration of the skin. It is caused by the oxidation of alpha-farnesene, a natural volatile compound, into toxic conjugated trienes. These oxidation products damage the epidermal cells, leading to their death and the characteristic appearance of the scald. Antioxidants and controlled atmospheres are often used to prevent this.

87. (D) High water content and short shelf life complicate storage and dosing
While fruits like tomatoes and bananas are attractive candidates for edible vaccines because they can be eaten raw, their high water content presents significant challenges. It makes the produce bulky to transport and highly perishable, complicating the logistics of storage and distribution. Additionally, the variable size and water content of individual fruits make it difficult to ensure consistent and accurate dosing for patients.

88. (A) Cytokinin to Abscisic acid/Ethylene
The onset of leaf senescence is regulated by a delicate balance between different hormones. Cytokinins generally act to maintain greenness and delay aging, while abscisic acid and ethylene promote the senescence program. A significant decrease in the ratio of cytokinin to these senescence-promoting hormones serves as a internal signal that triggers the dismantling of cellular structures and the remobilization of nutrients.

89. (A) III, IV, II, I
Chloroplast dismantling follows a precise biochemical sequence beginning with the removal of the phytol chain by chlorophyllase and the magnesium ion by Mg-dechelatase. Subsequently, the porphyrin ring of the resulting pheophorbide a is opened by pheophorbide a oxygenase. This leads to the formation of red chlorophyll catabolite, which is eventually reduced to produce the final primary fluorescent chlorophyll catabolites for vacuolar storage.

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143. (C) The plasma membrane
As seeds deteriorate during storage, one of the first things to fail is the structural integrity of the plasma membrane. When these seeds are soaked in water, the damaged membranes allow various ions and organic molecules to leak out into the surrounding solution. Measuring the electrical conductivity of this leachate provides a rapid and indirect way to assess the extent of membrane damage and overall seed vigor.

144. (A) Initial seed moisture content and genetic makeup
The longevity of a seed batch is determined by both external environmental factors and internal biological traits. The genetic makeup of the species defines its inherent storage potential, while the initial moisture content at the time of storage sets the baseline for its metabolic rate. These intrinsic factors, combined with the storage environment, determine how long the seeds will remain viable and capable of germinating.

145. (A) Double or triple for every $10^{\circ}C$ increase in temperature
The Q10 coefficient is a measure of how much the rate of a biological or chemical process increases with a ten-degree rise in temperature. For most non-chilling-sensitive plant tissues, the respiration rate and other metabolic activities approximately double or triple for every ten-degree Celsius increase. This relationship highlights why keeping produce cool is so effective at slowing down the overall rate of deterioration and extending shelf life.

146. (A) Leaf degradation aims at remobilization; fruit unmasks pigments
While chlorophyll is degraded in both senescing leaves and ripening fruits, the biological purpose is different. In leaves, the primary goal is to break down and remobilize the nitrogen and minerals from the photosynthetic complex to other parts of the plant. In many fruits, the degradation of chlorophyll primarily serves to unmask or allow the synthesis of other pigments, making the fruit more visible and attractive.

147. (C) It is extremely expensive to construct and maintain the physical facilities
Hypobaric storage involves keeping produce in a vacuum where the total air pressure is significantly reduced. This effectively lowers the concentration of oxygen and helps to draw out ethylene and other volatile gases from the fruit. While it is physiologically very effective at delaying ripening, the high cost of building and operating the necessary pressure-resistant facilities has limited its use to very high-value specialized applications.

148. (A) RNAi of ACO - Inhibits the final step of ethylene biosynthesis
RNA interference has been successfully used to target specific enzymes in the ethylene biosynthetic pathway. By silencing the gene for ACC oxidase, researchers can block the final step where ACC is converted into ethylene. This reduction in hormone levels effectively delays the ripening process and extends the shelf life of the fruit, providing a molecular tool for improving the quality of horticultural crops during transport.

149. (A) It has a small genome, easy transformability, and known mutants
The tomato has become the primary model for studying fruit ripening because it offers several scientific advantages. It is a relatively small plant with a well-characterized genome and is easily modified using genetic engineering techniques. Furthermore, the existence of several well-studied ripening mutants, such as rin and Nr, has allowed researchers to map out the complex hormonal and genetic networks that control the maturation process.

150. (D) A is false but R is true.
Climacteric fruits do not have to be fully ripe when harvested; in fact, they are often picked at a "mature green" stage for easier transport. This is possible because they possess the capacity for autocatalytic ethylene production, which allows them to complete the ripening process even after being detached from the parent plant. Therefore, the assertion is false, but the reason provided for their behavior is correct.

151. (A) Leaves act as nutrient sources for developing seeds (the sinks)
Monocarpic senescence is characterized by a dramatic shift in the plant's nutrient distribution. The leaves, which have spent their life producing and storing resources, transition into sources that are systematically dismantled. The nutrients released from this process are moved through the phloem to the developing seeds, which act as powerful sinks. This source-sink relationship

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186. (C) Enzymatic hydrolysis of stored starch into simple, sweet sugars
The primary reason many fruits become sweeter as they ripen is the conversion of stored starch into simple sugars like glucose, fructose, and sucrose. This process is driven by the activation of amylases and other hydrolytic enzymes during the final stages of maturation. As the complex carbohydrates are broken down, the concentration of soluble sugars in the fruit pulp increases, creating the sweet taste that is attractive to consumers.

187. (B) Potato (fed raw in clinical trials)
In early clinical trials of edible vaccines, the hepatitis B surface antigen was successfully expressed in transgenic potatoes. These potatoes were fed raw to human volunteers to test the immune response, as cooking would have destroyed the vaccine protein. While successful at inducing an immune response, the logistical challenge of consuming raw potatoes led researchers to look toward other crops like bananas or cereals for future vaccine delivery.

188. (A) Organized DNA cleavage and dismantling with intact membranes
Programmed cell death is distinguished from necrotic death by its orderly and controlled nature. During PCD, the cell undergoes a systematic dismantling of its components, including the organized cleavage of nuclear DNA and the breakdown of organelles, while the plasma membrane remains intact for a longer period. This ensures that the cell's contents are not spilled into the surrounding tissue, allowing for a clean and efficient recycling of resources.

189. (C) Calcium and boron
During the process of leaf senescence, plants are very efficient at remobilizing mobile nutrients like nitrogen, phosphorus, and potassium. However, some minerals, particularly calcium and boron, are considered immobile in the phloem. Once they are deposited in the leaf tissue, they cannot be easily moved to other parts of the plant. As a result, these nutrients remain locked in the senescing leaf and are eventually lost when it is shed.

190. (A) Both A and R are true and R is the correct explanation of A.
Edible vaccines are highly effective at triggering mucosal immunity because of the natural protection provided by the plant system. The rigid cellulose cell wall of the plant acts as a bio-encapsulation matrix that shields the vaccine antigens from being quickly degraded by the harsh acids in the stomach. This protection allows the antigens to reach the lymphoid tissues of the gut, where they can successfully induce the immune response.

191. (B) Shortening photoperiods and decreasing temperatures in the autumn
The timing of leaf fall in deciduous trees is primarily controlled by environmental signals that indicate the approach of winter. As the days get shorter and the temperatures begin to drop in the autumn, the trees perceive these changes and initiate the synchronous senescence and abscission of their leaves. This seasonal response is an adaptation that helps the trees conserve water and protect themselves from the damage of freezing temperatures.

192. (A) The respiratory climacteric burst providing ATP and carbon skeletons
The climacteric burst in ripening fruit is much more than just a surge in gas exchange; it is a period of intense metabolic activity. The increased respiration provides a high supply of ATP and various carbon-based intermediates needed for biosynthetic pathways. These resources are essential for the production of new compounds like anthocyanin pigments and volatile aromatic esters, which define the final appearance and flavor of the ripe fruit.

193. (C) The cellular and organellar lipid bilayer membranes
Lipid oxidation is a destructive chemical reaction that primarily affects the fatty acid components of the cellular membranes. During post-harvest storage, the buildup of reactive oxygen species leads to the peroxidation of these lipids, which compromises the fluid and semi-permeable nature of the bilayer. As the membranes lose their integrity, the cell can no longer maintain its internal compartments, leading to metabolic disruption and eventually tissue death.

194. (B) Specific microRNAs, primarily miR164
ORE1 is a key transcription factor that promotes the onset of leaf senescence, but its activity is strictly regulated to prevent premature aging. In young leaves, the expression of ORE1 is kept low through the action of a specific microRNA called

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Water core is characterized by translucent tissue due to sorbitol accumulation, and apple scald is the result of chemical oxidation products in the skin. Understanding these differences is essential for effective diagnosis and management.

161. (B) Stabilized because the F-box proteins EBF1/ EBF2 are degraded
In the presence of ethylene, the signaling pathway leads to the stabilization of the EIN3 transcription factors. Normally, EIN3 is targeted for degradation by the 26S proteasome through the action of F-box proteins EBF1 and EBF2. Ethylene signaling inhibits these proteins, allowing EIN3 to accumulate in the nucleus. Once stable, EIN3 can bind to its target promoters and activate the expression of genes involved in the ethylene response.

162. (A) Grains have low moisture and metabolic rates compared to fleshy fruits
Cereal grains and fleshy fruits have fundamentally different post-harvest physiologies. Grains are typically harvested at a dry stage, where their moisture content is very low and their metabolic rate is minimal. This allows them to be stored for years under proper conditions. In contrast, fleshy fruits have a high water content and remain metabolically active, making them much more perishable and susceptible to rapid decay.

163. (A) Metacaspases and specific endonucleases
The execution of programmed cell death in plants is a highly controlled process that involves the activation of specialized enzymes. Metacaspases, which are similar to animal caspases, play a key role in the proteolysis of specific cellular targets. Additionally, endonucleases are activated to dismantle the nuclear DNA in an orderly fashion. These enzymes ensure that the cell is broken down efficiently without causing harm to the surrounding living tissues.

164. (B) Prior to the onset of the climacteric respiratory burst
1-methylcyclopropene is most effective when it is applied to fruits before they have begun their major surge in ethylene production. By blocking the ethylene receptors early, the compound prevents the fruit from sensing the hormone that would normally trigger the autocatalytic ripening burst. This proactive treatment ensures that the ripening process is delayed as much as possible, maximizing the potential shelf life of the produce.

165. (B) Maintaining low temperatures and applying sprout suppressants like CIPC
Preventing potato tubers from sprouting is essential for maintaining their quality during long-term storage. This is typically achieved by keeping the storage facility at a consistently low temperature, which slows down the biological clock of the tuber. Additionally, chemical suppressants like CIPC are often applied to the tubers to inhibit the growth of the buds, ensuring that the potatoes remain firm and marketable for months.

166. (B) Maximum dry weight is reached and pods lose their green color
In legume crops like soybeans, physiological maturity is reached when the seeds have finished accumulating dry matter from the parent plant. This stage is visually indicated by the loss of the green color in the pods and the seeds. At this point, the vascular connection between the seed and the plant effectively shuts down, and the moisture content begins to drop as the seed prepares for harvest.

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167. (B) Low oxygen limits ethylene production by depriving the ACO enzyme
The enzyme ACC oxidase, which catalyzes the final step in ethylene biosynthesis, requires molecular oxygen to function. In controlled atmosphere storage, reducing the oxygen concentration to very low levels directly limits the activity of this enzyme. By starving the biosynthetic pathway of a necessary reactant, ethylene production is significantly reduced, which in turn delays the ripening and senescence of the stored fruits.

168. (C) Provide a respirable substrate to replace carbohydrate reserves
Cut flowers continue to respire after harvest, but they no longer have a steady supply of sugars from photosynthesis. Including sucrose in the holding solution provides an external source of energy that the flower can easily take up and use. This respirable substrate helps to maintain essential cellular processes, supports turgor pressure in the petals, and delays the onset of the wilting and death associated with carbohydrate starvation.

ensures that the plant's final reproductive effort is as successful as possible.

152. (A) A decrease in cell wall integrity and a rise in soluble sugars
As fruits ripen, they become increasingly susceptible to post-harvest pathogens. The enzymatic breakdown of cell walls softens the tissue, making it easier for fungal hyphae to penetrate. Simultaneously, the conversion of starch to soluble sugars provides an ideal nutrient source for the growth of microbes. These physiological changes, while desirable for human consumption, create an environment that is highly conducive to decay and rot.

153. (B) It acts as an inhibitor of ACC synthase, similar to AVG
Aminooxyacetic acid is a chemical compound that acts as an inhibitor of pyridoxal phosphate-dependent enzymes, including ACC synthase. By blocking the activity of this enzyme, AOA prevents the synthesis of ACC from SAM, effectively shutting down the ethylene production pathway. This makes it a useful tool in research for studying the role of ethylene in various plant processes, including ripening and flower senescence.

154. (B) Low, controlled concentrations of ethylene gas at optimal temperature and humidity
Citrus fruits are non-climacteric and do not ripen further after harvest, but they are often harvested when their peel is still partially green despite the internal pulp being mature. Commercial "degreening" is achieved by exposing the fruit to low levels of ethylene in a controlled environment. This treatment triggers the degradation of chlorophyll in the peel, unmasking the attractive yellow or orange pigments beneath.

155. (A) Occurrence of chilling injury and gray mold infection
Storing cut roses at temperatures near zero degrees Celsius is a common practice to extend their life, but it carries risks. While the cold slows down metabolism, it can also cause chilling injury in some varieties and creates a moist environment that encourages the growth of gray mold. This fungal pathogen can quickly damage the delicate petals, leading to a significant loss of quality and marketable value.

156. (A) Antigen synthesis in edible portions reduces vegetative metabolic drain
Using tissue-specific promoters in the production of edible vaccines ensures that the foreign protein is only expressed in the parts of the plant intended for consumption, such as the fruit or seeds. This prevents the unnecessary expenditure of energy and resources in the leaves and roots, where the antigen is not needed. By focusing production on the target tissue, the overall growth and health of the plant are better maintained.

157. (B) Ribulose-1,5-bisphosphate carboxylase/ oxygenase
The rapid decline in photosynthetic rate during leaf senescence is primarily due to the systematic breakdown of the chloroplast's internal proteins. RuBisCO, the enzyme responsible for carbon fixation, is targeted for early degradation because it contains a large amount of nitrogen. As this critical enzyme is dismantled and its components are remobilized, the leaf's ability to fix carbon dioxide and produce sugars is quickly lost.

158. (B) Senescence is negatively regulated by light and root-derived cytokinins
The rapid senescence of isolated leaves in the dark highlights that light and cytokinins are key negative regulators of the aging process. Light provides energy for continued metabolism, while cytokinins, which are normally produced in the roots and transported upward, act as potent anti-senescence signals. When a leaf is detached and kept in the dark, it loses both of these protective influences, triggering its programmed death.

159. (B) Natural respiration creates an equilibrium of low oxygen and high CO_2
Modified atmosphere packaging relies on the dynamic balance between the respiration of the produce and the gas permeability of the packaging film. As the vegetables breathe, they consume oxygen and release carbon dioxide within the sealed bag. Over time, an equilibrium is reached with lower oxygen and higher carbon dioxide levels than normal air, which effectively slows down the metabolic rate and extends the shelf life of the product.

160. (A) P-1, Q-2, R-3, S-4
Post-harvest disorders have distinct causes and symptoms. Chilling injury in bananas often appears as a dark browning of the peel, while bitter pit in apples is caused by calcium deficiency.

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stage is important for researchers and post-harvest specialists because it marks the boundary between the maturation phase and the onset of active ripening.

178. (A) Promote suberization and healing of wounds sustained during harvest
Sweet potatoes are often "cured" immediately after harvest by being placed in a warm, humid environment for several days. This treatment stimulates the rapid formation of a protective layer of suberin over any cuts or bruises obtained during digging. By healing these wounds, the curing process prevents excessive water loss and blocks the entry of decay-causing pathogens, greatly improving the storage life of the roots.

179. (A) Rapid moisture loss (wilting) and rapid chlorophyll degradation (yellowing)
Leafy vegetables like spinach and lettuce have a very high surface-area-to-volume ratio, making them exceptionally vulnerable to moisture loss after harvest. This rapid transpiration leads to wilting, which is the primary cause of quality loss. Furthermore, these vegetables undergo quick chlorophyll degradation, resulting in the yellowing of the leaves. Managing both humidity and temperature is essential to slow down these two prominent post-harvest deterioration processes.

180. (A) II, I, IV, III
The ripening of a climacteric fruit follows a logical sequence. It begins with the accumulation of low, baseline levels of ethylene (System 1). Once a certain threshold is reached, it triggers the autocatalytic production of massive amounts of ethylene (System 2). This hormonal surge is accompanied by a sharp rise in the respiration rate, which provides the energy needed for the subsequent changes in texture and pigment.

181. (B) Basic molecules that stabilize membranes and compete for SAM
Polyamines are naturally occurring basic molecules that can interact with negatively charged components of cellular membranes and proteins, providing structural stability during stress. Furthermore, they are thought to delay senescence by competing with the ethylene biosynthetic pathway for the common precursor, S-adenosylmethionine. By reducing the pool of SAM available for ethylene, polyamines can effectively slow down the hormone-driven processes that lead to tissue aging and death.

182. (B) Antisense ACS or ACO constructs, or mutated ethylene receptors
To extend the vase life of cut flowers like carnations, scientists have used genetic engineering to target the ethylene pathway. By introducing antisense constructs for ACC synthase or ACC oxidase, the flowers produce significantly less ethylene. Alternatively, expressing mutated ethylene receptors can make the plant insensitive to the hormone. Both approaches effectively delay the wilting of the petals, providing a way to improve the quality of commercial flowers.

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183. (A) Complete loss of green color in the peduncle below the head
In cereal crops, physiological maturity is reached when the grain has finished accumulating dry matter. A reliable morphological indicator of this stage is the loss of green color in the peduncle, the stem just below the grain head. When the peduncle turns yellow or brown, it signifies that the vascular connection has shut down and nutrient transport is complete. This marker helps farmers determine the optimal time for harvest.

184. (B) Rapid growth following stress causing internal tissue splitting
Hollow heart is a physiological disorder of potato tubers characterized by the formation of a star-shaped cavity in the center. It is not caused by a pathogen but by environmental conditions that favor extremely rapid tuber growth, especially following a period of stress. This sudden expansion causes the internal tissues to split apart under the mechanical tension, creating the hollow space that reduces the commercial quality of the crop.

185. (A) Life halves for every 1% moisture or 5 degree C temperature increase
Harrington's rules are general guidelines used to understand the relationship between environmental factors and seed longevity. They state that the storage life of a seed lot is approximately halved for every one percent increase in its moisture content or every five-degree Celsius increase in the storage temperature. These rules emphasize the critical importance of keeping seeds both dry and cool to maintain their viability over the long term.

169. (C) It primarily targets the highly saturated fatty acids in the cell membrane.
Lipid oxidation in seeds is a destructive process that specifically targets polyunsaturated fatty acids because they are chemically more vulnerable to attack by free radicals. This reaction leads to the production of lipid hydroperoxides, which further break down and damage the structural integrity of cellular membranes. Saturated fatty acids are much more stable and are not the primary targets of this type of oxidative deterioration during storage.

170. (A) II and IV
Molecular approaches to improving shelf life are highly specific. Antisense and RNAi technologies do not irreversibly alter the plant's entire genomic DNA sequence; they target the expression of specific genes at the RNA level. Furthermore, while suppressing polygalacturonase helps maintain fruit firmness by slowing cell wall breakdown, it does not directly block the production of ethylene, which is controlled by a completely separate set of biosynthetic enzymes.

171. (A) Maintain efficient upper leaves while recycling nutrients from older ones
Progressive senescence is an adaptive strategy that allows cereal crops to optimize their resources during growth. By systematically dismantling the oldest, shaded leaves at the base of the plant, the crop can remobilize essential nutrients to the younger, more productive leaves at the top. This ensures that the upper foliage remains photosynthetically active for as long as possible, which is critical for maximizing grain development and yield.

172. (B) The central vacuole
As chlorophyll is broken down during leaf senescence, it is converted through a series of steps into colorless catabolites known as non-fluorescent chlorophyll catabolites. These final products are actively transported into the central vacuole, where they are permanently sequestered. This storage prevents the catabolites from accumulating in the cytoplasm, where they could potentially interfere with other cellular processes or become toxic if exposed to light.

173. (B) Rapid and coordinated senescence occurs after pollination or lifespan
Flower senescence is often more rapid and coordinated than leaf senescence, as it is frequently triggered by a specific event like pollination. Once the flower's primary purpose of reproduction is achieved, or its biological lifespan is over, the plant initiates a fast-acting death program to recycle the nutrients stored in the petals. This ensure that energy is redirected toward the developing ovary and seeds.

174. (B) Emasculation or successful pollination
In many orchid species, the process of pollination or the physical removal of the pollinia (emasculation) triggers an immediate and massive surge in ethylene production. This hormonal burst acts as a signal that the flower's reproductive role is complete, leading to the rapid wilting and senescence of the petals. This coordinated response allows the plant to quickly begin redirecting its resources toward the development of the fruit.

175. (B) The antioxidant defense system including SOD, APX, and catalase
Chilling injury at low temperatures triggers the excessive production of reactive oxygen species within the plant cells. Under normal conditions, these are managed by the antioxidant defense system, which includes enzymes like superoxide dismutase and catalase. However, during severe chilling stress, this protective system is often overwhelmed, allowing the ROS to cause extensive damage to membranes and proteins, resulting in tissue death.

176. (C) Biological oxygen depletion and carbon dioxide rise by grain/insect respiration
Hermetic storage is a low-cost, effective method for protecting stored grain that relies on creating an airtight environment. Within the sealed container, the natural respiration of the grain and any resident insects quickly uses up the available oxygen and increases the concentration of carbon dioxide. This change in gas levels eventually reaches a point where it inhibits the growth of fungi and kills the insects, protecting the grain.

177. (A) The lowest respiration rate preceding the subsequent climacteric rise
The "climacteric minimum" is a specific physiological point in the development of certain fruits. It represents the lowest level of respiration reached after the fruit has completed its growth but before it begins the dramatic respiratory burst associated with ripening. Identifying this

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miR164. As the leaf gets older, the concentration of this microRNA decreases, allowing ORE1 levels to rise. This molecular switch is essential for ensuring that senescence begins at the appropriate time.

195. (A) MAP is less expensive and maintains the atmosphere during transport
Modified atmosphere packaging offers several practical advantages over controlled atmosphere storage. It is much less expensive to implement because it does not require complex mechanical equipment to monitor gas levels. Furthermore, because the atmosphere is created and maintained within the individual package, it continues to protect the produce throughout the entire distribution chain, including transport and retail display, where CA storage is not possible.

196. (A) Decreasing temperature exponentially slows respiration and decay
Temperature is the single most important factor in post-harvest management because of its profound effect on biological reaction rates. By cooling produce, the respiration rate is exponentially reduced, which slows down the consumption of energy reserves and the production of heat. Additionally, low temperatures inhibit the growth of most decay-causing fungi and bacteria, significantly extending the amount of time the produce remains fresh and safe for consumption.

197. (C) Providing a microenvironment for the growth of fungal spores
The presence of free water on the surface of seeds or fruits is highly detrimental to their storage life. Moisture creates a localized environment that is ideal for the germination and growth of fungal spores and bacteria. These microorganisms can quickly penetrate the tissue, leading to rapid decay and rot. Maintaining dry surfaces through proper ventilation and humidity control is a fundamental practice in post-harvest handling.

198. (A) Pectin
The middle lamella is a specialized layer of the cell wall that serves as the intercellular cement, holding adjacent plant cells together. It is primarily composed of pectic substances, particularly calcium pectate. During the fruit ripening process, enzymes specifically target and break down these pectins, causing the cells to pull apart. This biochemical dismantling of the middle lamella is the direct cause of the softening texture observed in ripening fruit.

199. (B) Up-regulation of enzymes driving an intense spike in CO_2 evolution
The climacteric peak is characterized by a significant surge in metabolic activity as the fruit completes its ripening program. This period involves the upregulation of various enzymes that facilitate the intensive breakdown of substrates, leading to a sharp increase in the evolution of carbon dioxide. This respiratory burst is essential for generating the energy and building blocks needed for the final synthesis of pigments, aromas, and sugars in the fruit.

200. (A) P-3, Q-2, R-1, S-4
Edible vaccines rely on several key components. Mucosal immunity is the primary defense triggered in the gut, while the plant cell wall provides bio-encapsulation to protect the antigen. The cholera toxin B subunit is often used as an adjuvant to enhance the immune response. Transgenic expression is the genetic process by which the plant is engineered to produce these foreign antigens in its edible tissues.

201. (A) Suberin and lignin
Before a leaf is shed through abscission, the plant forms a protective layer on the stem side of the separation zone. This layer is reinforced with suberin and lignin, which are waterproof and resistant to decay. This "cork-like" seal is essential for protecting the plant's internal vascular system from water loss and the entry of pathogens once the leaf has fallen, ensuring that the remaining tissue remains healthy.

202. (B) Lethal desiccation damage if dried below fifteen to thirty percent moisture
Mango and rubber tree seeds are examples of recalcitrant seeds, which cannot survive the drying process that is standard for long-term storage in gene banks. If their moisture content drops below a relatively high threshold, they suffer irreversible damage to their cellular membranes and embryos. This sensitivity to desiccation makes it impossible to preserve them using traditional low-moisture and freezing techniques, requiring alternative conservation methods.

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membranes. As the lipids transition from a fluid to a gel state, the proteins of the electron transport chain become misaligned or uncoupled. This disruption causes electrons to be transferred directly to oxygen, creating a surge of ROS that overwhelms the cell's antioxidant defenses and leads to oxidative damage.

221. (B) Fully developed seeds allowing ripening after fruit detachment
Physiological maturity in a fleshy fruit like a tomato occurs when the seeds have reached a stage where they are fully developed and capable of germinating. At this point, even if the fruit is still green, it has the biological capacity to complete its ripening process if it is removed from the parent plant. This stage is a critical transition point that allows the fruit to be harvested for transport while still being able to reach high quality.

222. (A) Isoamyl acetate
Isoamyl acetate is the primary volatile ester responsible for the characteristic sweet aroma of a ripening banana. It is synthesized in large quantities during the final stages of fruit maturation as part of the complex mix of volatile compounds that attract animals. In the food industry, this specific compound is also used as a synthetic flavor to mimic the natural scent and taste of bananas in various products.

223. (A) Epigenetic demethylation of the target gene promoters
Recent research has shown that the initiation of fruit ripening in tomatoes is controlled by more than just hormones; it also involves significant epigenetic changes. As the fruit matures, the promoters of many ripening-related genes, including those for the RIN transcription factor, undergo demethylation. This removal of methyl groups opens up the DNA structure, allowing RIN and other regulators to bind and activate the genes needed for the ripening process to proceed.

224. (A) Cut the stem ends underwater
Cutting flower stems in the air can allow air to be sucked into the xylem vessels, creating embolisms that block the flow of water. By performing the final cut underwater, the plant is exposed only to a continuous supply of water, which prevents air from entering the system. This simple practice helps to maintain a continuous water column within the stem, ensuring that the flower remains fully hydrated and firm for a longer time.

225. (A) I, II, III and V
Fruit softening is a multi-enzymatic process that targets the various components of the cell wall. Pectin methylesterase prepares pectins for further degradation by polygalacturonase, while cellulases and hemicellulases break down the structural framework of the wall. Expansins also play a role by loosening the non-covalent bonds between polymers. These coordinated activities lead to the overall loss of tissue firmness. However, lignification is not part of this softening process.

226. (A) Storage depots for lipid breakdown products from the membranes
Plastoglobuli are spherical lipid droplets found within the chloroplast. During leaf senescence, as the internal thylakoid membranes are dismantled, the released lipids and chlorophyll catabolites are temporarily sequestered in these structures. They serve as essential storage depots that prevent these potentially toxic breakdown products from accumulating in the rest of the cell. As the senescence process continues, the contents of these plastoglobuli may be further processed or remobilized for recycling.

227. (A) Ethylene triggers the peak in one but only transient respiration in another
Climacteric and non-climacteric fruits show fundamentally different responses to exogenous ethylene. In climacteric fruits, even a brief exposure to ethylene can trigger the permanent onset of the respiratory burst and autocatalytic ethylene production. In contrast, non-climacteric fruits may show a temporary increase in respiration as long as the ethylene is present, but they return to their baseline once the treatment stops and do not initiate a self-sustaining ripening burst.

228. (A) Sucrose converts to starch, causing sweetness loss if not cooled
The loss of quality in sweet corn after harvest is primarily due to the rapid conversion of sugars into starch within the kernels. This metabolic process is driven by enzymes that remain highly active at warm temperatures. To prevent this loss of sweetness, it is critical to pre-cool the corn immediately after harvest and maintain it at a low temperature, which significantly slows down the rate of starch synthesis.

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instead, it blocks the ethylene receptors so the plant cannot sense or respond to the hormone. This difference determines how each chemical is used in post-harvest management.

212. (A) The leaf tip and margins
In many monocots, leaf senescence does not occur all at once but follows a specific spatial pattern across the leaf blade. The process typically begins at the tip and along the outer margins, where the tissue is oldest and furthest from the main vascular supply. From there, the yellowing and death move gradually toward the base and the midrib until the entire leaf has been dismantled for nutrient remobilization.

213. (A) Adequate and consistent expression of the antigen in the tissues
A major hurdle in the development of edible vaccines is ensuring that the transgenic plant produces enough of the antigen to be effective. The expression levels must be high and consistent across different plants and environments to ensure that a predictable dose is delivered when the produce is eaten. Researchers use various molecular strategies, such as strong promoters and codon optimization, to maximize the synthesis of the foreign vaccine protein.

214. (A) The mitochondrion
During the orderly dismantling of a senescing leaf, the mitochondrion is one of the last organelles to lose its structural and functional integrity. This is essential because the process of nutrient remobilization is energy-intensive and requires a steady supply of ATP. By keeping the mitochondria active until the very end, the cell ensures it has the energy needed to successfully load amino acids and minerals into the phloem for transport.

215. (C) III and IV
The ripening of climacteric fruits is a complex process that involves a shift to autocatalytic ethylene production and a corresponding surge in respiration. However, fruit softening is caused by the breakdown of the cell wall, not the synthesis of new cellulose. Similarly, color changes are due to the synthesis or unmasking of pigments, while starch is actually hydrolyzed into sugars rather than being accumulated in the mature fruit.

216. (A) Carnauba wax or synthetic resin waxes
Citrus fruits are frequently treated with a thin layer of wax after harvest to improve their appearance and extend their storage life. These waxes, which can be natural or synthetic, fill in small pores on the peel, significantly reducing the rate of water loss through transpiration. This treatment helps to keep the fruit firm and juicy for a longer period while also giving it a shiny, attractive finish for the retail market.

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217. (A) Predict vigor and longevity by subjecting seeds to stress conditions
Accelerated aging is a critical tool for seed technologists because it allows them to quickly evaluate the quality of a seed lot. By exposing the seeds to high temperature and humidity, they can simulate the effects of several months of natural storage in just a few days. This test helps to identify seed batches that are likely to lose their viability quickly in the warehouse, allowing for better inventory management and quality control.

218. (A) Reduced ethylene production, delaying ripening and extending shelf-life
Using antisense technology to target ACC oxidase provides a way to directly control the amount of ethylene a fruit can produce. In transgenic tomatoes, this reduction in hormone levels leads to a significant delay in the onset of ripening and a much slower rate of softening after the fruit begins to mature. This technology allows the fruit to reach its full flavor while maintaining the firmness needed for long-distance transport.

219. (A) Retained for functional roles like water transport or structural support
In many cases, the cells that undergo programmed cell death in plants are not just discarded; they are kept for specific functional purposes. The most prominent example is the formation of xylem vessels, where the cells die to create hollow tubes for water transport. Similarly, some structural fibers remain in the plant after death to provide mechanical support. This strategy allows the plant to use the "skeletons" of its dead cells.

220. (A) Uncoupling of the electron transport chain due to phase transitions
The massive production of reactive oxygen species during chilling injury is often triggered by changes in the mitochondrial and chloroplast

203. (A) Deposition of suberin by the xylem parenchyma leading to occlusion
The vase life of cut flowers is often limited by a decrease in water uptake, which can be caused by the plant's own physiological response to the wound. In some cases, the xylem parenchyma cells respond to the cut by depositing suberin and other materials into the vessels. This biological occlusion, combined with bacterial growth and air bubbles, creates a physical barrier that prevents water from reaching the flower head.

204. (B) Competitive inhibition of ethylene action and suppressed respiration
Exposing climacteric fruits to high concentrations of carbon dioxide post-harvest can effectively slow down the ripening process. Carbon dioxide acts as a competitive inhibitor of ethylene, preventing the hormone from binding to its receptors and triggering its usual effects. Additionally, high CO_2 levels directly suppress the overall respiration rate of the tissue, further delaying the metabolic changes that lead to softening and quality loss during storage.

205. (D) II
Senescence-associated genes are a diverse group of genes that are upregulated as a leaf ages. While many of them do encode destructive enzymes like proteases and nucleases for dismantling the cell, others play positive roles in the survival of the rest of the plant. These include genes involved in the remobilization and transport of nitrogen and other nutrients from the aging leaf to more productive organs.

206. (A) Application of maleic hydrazide and maintaining low humidity
Controlling sprouting is the most important factor in maintaining the quality of stored onions and garlic. Farmers often apply maleic hydrazide in the field before harvest to inhibit the future growth of the bulbs. During storage, keeping the humidity low prevents the bulbs from absorbing the moisture that would normally trigger the breaking of dormancy, allowing the crop to remain firm and marketable for much longer.

207. (A) A single reproductive cycle followed by senescence and death
Monocarpic plants are characterized by their "once-only" reproductive strategy. They spend their life growing vegetatively until they reach maturity, at which point they produce flowers and seeds in a single, often massive event. Following this reproductive phase, the entire plant undergoes a coordinated senescence and dies. Common examples include annual crops like wheat and soybean, as well as some long-lived perennials like certain species of bamboo.

208. (A) Degradation of chlorophyll and massive de novo synthesis of lycopene
The dramatic color change in a ripening tomato is the result of two simultaneous biochemical processes. First, the green chlorophyll that dominates the immature fruit is enzymatically broken down and disappears. At the same time, the fruit begins the massive new synthesis of lycopene, a red carotenoid pigment. This combination of events transforms the fruit's appearance, signaling to animals and consumers that it is ripe and ready to eat.

209. (C) Bacteria
Ethylene perception in plants is unique because it utilizes a signaling mechanism that is evolutionarily related to the two-component systems found in bacteria. These systems typically involve a sensor kinase and a response regulator. In plants, the ethylene receptors function as the sensor kinases, but the pathway has been adapted to include several additional steps before the signal reaches the nucleus to activate the transcription of ethylene-responsive genes.

210. (A) Anaerobic respiration due to extremely low internal oxygen levels
Off-flavors in stored fruits are frequently caused by a shift from aerobic to anaerobic respiration. This occurs when the oxygen level within the tissue drops too low, either due to poor ventilation or an over-tight coating. The resulting fermentation produces ethanol and acetaldehyde, which impart a fermented or "off" taste to the fruit. Avoiding these conditions is critical for maintaining the high sensory quality of produce after harvest.

211. (A) AVG blocks ACS biosynthesis; 1-MCP blocks receptor perception
Although both AVG and 1-MCP are used to delay ripening, they target different parts of the ethylene pathway. AVG works by inhibiting the enzyme ACC synthase, thereby preventing the plant from producing its own ethylene. In contrast, 1-MCP does not stop ethylene production;

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229. (A) Stronger knockdown of target genes due to its catalytic mechanism
RNA interference is often more effective than traditional antisense technology because it utilizes a catalytic mechanism to degrade the target messenger RNA. A single double-stranded RNA molecule can trigger the destruction of multiple mRNA transcripts, leading to a much stronger and more consistent knockdown of the target gene's expression. This increased efficiency makes RNAi a preferred tool for researchers looking to significantly modify the ripening or senescence of horticultural crops.

230. (A) They decrease as guard cells lose functionality and responsiveness
As leaves undergo the natural process of senescence, they experience a significant reduction in stomatal conductance. This physiological change occurs because the guard cells lose their turgor and become less responsive to internal and external signals. Consequently, the transpiration rate drops, reflecting the overall decline in metabolic activity and the functional dismantling of the leaf's primary gas exchange structures during the final stages of its life.

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(A) Abscisic acid
(B) Cytokinin
(C) Ethylene
(D) Salicylic acid

2022

22. Consider the following statements concerning the plant cell cycle:
I. CDKA is functional throughout the entire cell cycle.
II. B-type CDKs are unique to plants and function strictly at the G2/M transition.
III. Endoreduplication involves repeated S phases without cytokinesis.
IV. KRPs (Kip-related proteins) enhance CDK activity.
Which of the above statement(s) is/are correct?
(A) I, II and III
(B) II, III and IV
(C) I and IV
(D) II and IV

2022

23. In the context of the plant cell cycle, endoreduplication directly results in cells that exhibit:
(A) Haploidy
(B) Aneuploidy
(C) Nullisomy
(D) Polyploidy

2024

24. Abscisic acid (ABA) typically exerts what effect on the plant cell cycle during stress conditions?
(A) Induction of CDK inhibitors
(B) Acceleration of the G2/M transition
(C) Upregulation of B-type cyclins
(D) Promotion of RBR protein degradation

2022

25. Which specific cyclin class associates with CDKA to regulate the transition from G2 to mitosis?
(A) D-type cyclins only
(B) A-type and B-type cyclins
(C) H-type cyclins
(D) C-type cyclins

2024

26. Select the correct sequence of regulatory events initiating the S phase in plants.
(A) E2F activation → RBR phosphorylation → S-phase gene transcription
(B) RBR phosphorylation → E2F activation → S-phase gene transcription
(C) S-phase gene transcription → E2F activation → RBR phosphorylation
(D) RBR phosphorylation → S-phase gene transcription → E2F activation

2024

27. The destruction of mitotic cyclins, allowing exit from mitosis, is executed by which protein complex?
(A) Anaphase-promoting complex (APC/C)
(B) Pre-replication complex
(C) Regulatory SCF complex
(D) Origin recognition complex

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2024

28. Phytochromes are homodimeric chromoproteins that primarily perceive which specific wavelengths of light?
(A) Blue and UV-A
(B) Green and yellow
(C) Red and far-red
(D) UV-B and UV-C

2025

29. The light-absorbing chromophore covalently attached to the plant phytochrome apoprotein is:
(A) Flavin mononucleotide
(B) Beta-carotene
(C) Zeaxanthin
(D) Phytochromobilin

2002

30. Which specific amino acid residue in the phytochrome apoprotein is bonded to the chromophore via a thioether linkage?
(A) Serine
(B) Tyrosine
(C) Cysteine
(D) Histidine

2018

31. Upon absorbing red light, the Pr form of phytochrome undergoes a conformational change to the Pfr form. This transformation involves:
(A) A trans-to-cis isomerization of the chromophore
(B) A cis-to-trans isomerization of the chromophore
(C) Phosphorylation of the chromophore
(D) Cleavage of the thioether bond

2019

32. Consider the following statements regarding phytochrome structural properties:
I. The N-terminal half contains the photosensory core.
II. The C-terminal half contains the dimerization

2005

10. Cellular polarity in root hairs is characterized by which specific type of growth mechanism?
(A) Diffuse growth
(B) Tip growth
(C) Intercalary growth
(D) Secondary growth

2010

11. In tip-growing pollen tubes, the apical clear zone is predominantly enriched in which cellular components?
(A) Secretory vesicles
(B) Large central vacuoles
(C) Chloroplasts
(D) Mature mitochondria

2010

12. Consider the following statements regarding cytoskeletal dynamics in tip-growing plant cells:
I. A highly dynamic actin cytoskeleton dominates the apical region.
II. Cortical microtubules are the primary drivers of apical vesicle transport.
III. The calcium ion gradient is highest at the extreme apex.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I and III
(C) II
(D) II and III

2010

13. Which cellular gradient is absolutely essential for maintaining polarity and directing vesicle fusion in growing pollen tubes?
(A) Potassium gradient
(B) Sodium gradient
(C) Chloride gradient
(D) Calcium gradient

2024

14. Diffuse growth differs from tip growth primarily because diffuse growth involves:
(A) Vesicular exocytosis limited to the apical dome
(B) Total lack of cortical microtubule activity
(C) Global surface-level expansion
(D) Localized inhibition of cellulose synthases

2007

15. Which feature is universally characteristic of cells undergoing highly polarized tip growth?
(A) Uniform deposition of hemicellulose chains
(B) Apex-restricted wall loosening
(C) Fixed nuclear positioning during elongation
(D) Functional absence of the Golgi apparatus

2009

16. In the elongation zone of roots, cell expansion is largely regulated by the interplay between which two structural elements?
(A) Actin filaments and the tonoplast
(B) Endoplasmic reticulum and plasmodesmata
(C) Nuclear envelope and intermediate filaments
(D) Cortical microtubules and cellulose microfibrils

2008

17. The precise delivery of cell wall components to the apex of a growing root hair depends heavily on:
(A) Actin-myosin directed vesicular trafficking
(B) Passive diffusion of pectin units
(C) Microtubule depolymerization events
(D) Vacuolar expansion-based forces

2010

18. Which statement regarding cellular polarity establishment in zygotes of Fucus (a model for plant polarity) is correct?
(A) Polarity is strictly predetermined by maternal genetics.
(B) Cytoskeletal elements are entirely degraded during polarization.
(C) Light direction dictates the site of rhizoid outgrowth.
(D) The calcium gradient forms only after the first cell division.

2024

19. The plant cell cycle is primarily driven by the periodic activation of which distinct class of enzymes?
(A) Cyclin-dependent kinases (CDKs)
(B) Regulatory phosphatases
(C) Signaling MAP kinases
(D) Cyclic adenylyl cyclases

2001

20. The transition from G1 to S phase in plant cells requires the degradation of which specific regulatory proteins?
(A) D-type cyclins
(B) A-type CDKs
(C) E2F factors
(D) Retinoblastoma-related (RBR) proteins

2024

21. Which plant hormone is the most prominent positive regulator of D-type cyclin (CYCD) expression, pushing cells into the cycle?

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CHAPTER 12

Morphogenesis, Tissue Culture and Plant Transformation

NODIA

2011

1. Which cytoskeletal structure accurately predicts the plane of cell division in plant cells before mitosis begins?
(A) Preprophase band
(B) Phragmoplast
(C) Cell plate
(D) Spindle apparatus

2005

2. The primary driving force for plant cell expansion during the elongation phase is generated by which mechanism?
(A) Increased cell wall rigidity via lignification
(B) Rapid synthesis of secondary metabolites in vacuoles
(C) Cellulose-guided turgor pressure
(D) Breakdown of middle lamella by enzymatic action

2003

3. During plant cytokinesis, the phragmoplast is primarily composed of which cytoskeletal elements?
(A) Microtubules and actin filaments
(B) Specific intermediate filaments only
(C) Myosin and dynein motor proteins
(D) Membrane-bound cellulose synthases

2018

4. According to the acid growth hypothesis, which enzyme is activated by a decrease in apoplastic pH to facilitate cell wall loosening?
(A) Cellulase
(B) Pectin methylesterase
(C) Xyloglucan endotransglucosylase
(D) Expansin

2010

5. In which specific phase of the plant cell cycle does the preprophase band typically form?
(A) Early G1 phase
(B) S phase
(C) G2 phase
(D) Late anaphase

2022

6. Which statement INCORRECTLY describes the orientation of cellulose microfibrils during diffuse growth?
(A) They are deposited perpendicular to the axis of elongation.
(B) Their deposition is guided by cortical microtubules.
(C) They are randomly oriented in elongating cells.
(D) They prevent lateral expansion of the cell.

2013

7. The synthesis of new cell wall material at the cell plate is primarily mediated by vesicles derived from which organelle?
(A) Endoplasmic reticulum
(B) Central vacuole
(C) Mitochondria
(D) Golgi apparatus

2007

8. In differentiating plant cells, secondary cell wall deposition occurs strictly after which process is complete?
(A) Cell expansion
(B) Chromosome condensation
(C) DNA replication
(D) Phragmoplast formation

2017

9. Which combination accurately pairs a cytological structure with its primary functional role in plant growth?
(A) Preprophase band - guides vesicle fusion at the cell plate
(B) Cortical microtubules - align cellulose deposition
(C) Phragmoplast - determines future division planes
(D) Actin microfilaments - generate high turgor pressure

domain.
III. Phytochromobilin is synthesized entirely in the cytoplasm.
IV. Pfr is the biologically active form for most responses.
V. The Pr form absorbs maximally at 660 nm.
Which of the above statement(s) is/are INCORRECT?
(A) I, II and IV
(B) I, IV and V
(C) III only
(D) II, III and V

2019

33. Phytochromobilin biosynthesis originates in which plant cell organelle?
(A) Plastid
(B) Nucleus
(C) Endoplasmic reticulum
(D) Peroxisome

2012

34. Which phytochrome family member in Arabidopsis is primarily considered light-labile (Type I)?
(A) PhyB
(B) PhyC
(C) PhyA
(D) PhyE

2023

35. Which statement best describes the absorption maximum of the Pfr form of phytochrome?
(A) 450 nm
(B) 660 nm
(C) 730 nm
(D) 800 nm

2014

36. Dark reversion is a physiological process where:
(A) Pr converts to Pfr without light.
(B) The chromophore is degraded in the dark.
(C) Phytochrome migrates from the nucleus to the cytosol.
(D) Pfr spontaneously reverts to Pr independent of light.

2014

37. Following activation by red light, the Pfr form of phytochrome primarily translocates to which cellular compartment?
(A) Chloroplast
(B) Nucleus
(C) Plasma membrane
(D) Vacuole

2021

38. Phytochrome Interacting Factors (PIFs) fundamentally function as:
(A) Kinases for phytochrome phosphorylation
(B) Ligases for protein polyubiquitination
(C) Negative regulators of light signaling
(D) Antenna proteins for light harvesting

2015

39. In the dark, the COP1/SPA complex promotes skotomorphogenesis by actively performing which molecular function?
(A) Phosphorylating the inactive Pr phytochrome
(B) Stabilizing the active Pfr phytochrome form
(C) Inducing nuclear chloroplast gene expression
(D) Targeting positive regulators for degradation

2013

40. Upon light activation and nuclear translocation, Pfr directly interacts with PIFs, resulting in:
(A) Phosphorylation and degradation of PIFs
(B) Long-term stabilization of PIF proteins
(C) Active export of PIFs to the cytosol
(D) Activation of PIF-mediated transcription

2015

41. Which key transcription factor is positively stabilized in the light to promote photomorphogenesis?
(A) PIF3
(B) HY5
(C) COP1
(D) SPA1

2025

42. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): Under continuous light, the COP1 protein migrates from the nucleus to the cytoplasm.
Reason (R): Cytoplasmic localization prevents COP1 from ubiquitinating its nuclear targets like HY5.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2014

43. Which molecular event correctly describes the mechanism by which phytochrome disables the COP1/SPA complex in the light?
(A) Pfr binds to SPA, disrupting the COP1-SPA

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2006

64. A cell that has undergone dedifferentiation but has not yet received signals directing it to form a specific organ is currently in a state of:
(A) Senescence
(B) Terminal differentiation
(C) Irreversible determinism
(D) Undifferentiated plasticity

2019

65. The Murashige and Skoog (MS) medium is universally recognized for its unusually high concentration of which essential inorganic nutrients?
(A) Ammonium and nitrate salts
(B) Calcium and magnesium
(C) Phosphate and sulfate
(D) Sodium and chloride

2022

66. In standardized plant tissue culture media, which organic compound is universally added as the primary exogenous carbon and energy source?
(A) Glucose
(B) Fructose
(C) Sucrose
(D) Mannitol

2008

67. Myo-inositol is frequently included in plant tissue culture media primarily to facilitate:
(A) Phospholipid biosynthesis and cell wall formation
(B) Nitrogen fixation
(C) Chlorophyll degradation
(D) Rapid stomatal closure

2017

68. Which micronutrient in MS medium is provided as a chelated complex with EDTA to maintain its solubility over a wide pH range?
(A) Zinc
(B) Copper
(C) Boron
(D) Iron

2016

69. The optimal pH range for most plant tissue culture media, set prior to autoclaving, typically falls between:
(A) 4.0 - 4.5
(B) 5.6 - 5.8
(C) 6.8 - 7.2
(D) 7.5 - 8.0

2010

70. Activated charcoal is occasionally added to tissue culture media specifically to:
(A) Supplying an alternative carbon source
(B) Enhancing the media's osmotic potential
(C) Adsorbing inhibitory phenolic compounds
(D) Indicating pH changes through color

2012

71. Vitamins, particularly Thiamine (B1), are added to culture media because they function fundamentally as:
(A) Structural components of the cell wall
(B) Primary energy reserves
(C) Direct inducers of somatic embryogenesis
(D) Coenzymes for critical metabolic pathways

2004

72. Consider the following statements concerning tissue culture media components:
I. Agar is the most common solidifying agent because it is easily digested by plant cells.
II. Macronutrients are typically required in millimolar (mM) concentrations.
III. Copper and molybdenum are classified as micronutrients.
IV. Sucrose acts as both a carbon source and an osmoticum.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) II, III and IV
(C) I and III
(D) I, III and IV

2010

73. Which of the following is typically categorized as a complex, undefined organic supplement in tissue culture?
(A) Glycine
(B) Coconut milk
(C) Nicotinic acid
(D) Potassium nitrate

2021

74. According to the classical model proposed by Skoog and Miller, an exceptionally high ratio of auxin to cytokinin in the medium induces the formation of:
(A) Shoots
(B) Roots
(C) Flowers
(D) Unorganized callus only

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(D) Ethylene perception

2025

54. In etiolated seedlings, the apical hook is maintained primarily by the action of which hormone, with its signaling later altered by phytochrome to promote hook opening?
(A) Salicylic acid
(B) Gibberellin
(C) Ethylene
(D) Jasmonic acid

2005

55. Seed germination in small-seeded plants is often positively regulated by phytochrome to ensure:
(A) Seeds germinate deep in the soil profile.
(B) Seedlings emerge only when the canopy is dense.
(C) Germination relies exclusively on stored starch reserves.
(D) Germination occurs near the surface in adequate light.

2005

56. The inherent genetic capacity of a single isolated plant cell to regenerate into a completely viable, fertile adult plant is strictly termed:
(A) Totipotency
(B) Pluripotency
(C) Determinism
(D) Competency

2009

57. In the context of cellular differentiation, "competency" is best defined as:
(A) Permanent loss of various regenerative capacities
(B) Responsiveness to specific developmental signals
(C) Terminal state of a fully matured cell type
(D) Fusion event between two distinct protoplasts

2013

58. Pluripotency in plant systems conceptually differs from totipotency because pluripotent cells:
(A) Cannot divide under any conditions.
(B) Can form multiple tissue types but not an entire fertile organism.
(C) Are restricted solely to generating reproductive organs.
(D) Lack a functioning nucleus.

2006

59. The transition of a differentiated mesophyll cell into an actively dividing callus cell requires which fundamental biological process?
(A) Dedifferentiation
(B) Redifferentiation
(C) Somatic crossing over
(D) Apoptosis

2019

60. Determinism in cellular development refers to the state where a cell's developmental fate is:
(A) Entirely flexible and easily altered by media changes.
(B) Dependent solely on gravity.
(C) Locked in and irreversibly committed to a specific lineage.
(D) Controlled exclusively by chloroplast DNA.

2017

61. Totipotency was theoretically proposed long before it was practically demonstrated. Which scientist is credited with formulating the concept of plant cell totipotency in 1902?
(A) F.C. Steward
(B) P.R. White
(C) E.C. Cocking
(D) Gottlieb Haberlandt

2006

62. Consider the following statements regarding totipotency and dedifferentiation:
I. Dedifferentiation is accompanied by cellular reprogramming and reentry into the cell cycle.
II. Mature companion cells are the easiest to dedifferentiate.
III. Competence must be acquired before a dedifferentiated cell is determined for a new pathway.
Which of the above statement(s) is/are correct?
(A) I
(B) I and II
(C) I and III
(D) II

2011

63. Epigenetic reprogramming during the acquisition of totipotency primarily involves which molecular alterations?
(A) Complete elimination of the cell wall
(B) Altered DNA methylation and histone acetylation
(C) Deletion of senescence-associated genes
(D) Rapid mutation of chloroplast genomes

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interaction.
(B) Phytochrome degrades SPA proteins directly.
(C) Pfr heavily phosphorylates COP1 to induce its degradation.
(D) Pfr competes with HY5 for binding to DNA.

2023

44. The Very Low Fluence Response (VLFR) of phytochrome is characterized by which unique feature?
(A) It requires prolonged exposure to high-intensity red light.
(B) It is perfectly photoreversible by far-red light.
(C) It mediated by PhyA and is not far-red reversible.
(D) It exclusively governs the shade avoidance syndrome.

2017

45. Which regulatory mechanism prevents the hyperaccumulation of PhyA in prolonged light?
(A) Pr form of PhyA inhibits its own transcription.
(B) Light completely halts translation of PhyA mRNA.
(C) PIF proteins degrade PhyA.
(D) Pfr form of PhyA is targeted for ubiquitin degradation.

2005

46. Arrange the following events of phytochrome signaling in correct temporal sequence.
I. Chromophore isomerization
II. Nuclear translocation
III. Absorption of 660 nm light
IV. Interaction with PIFs
(A) III → I → II → IV
(B) I → III → IV → II
(C) III → II → I → IV
(D) I → II → III → IV

2001

47. Photomorphogenesis in dicot seedlings is classically characterized by:
(A) Acceleration of hypocotyl elongation
(B) Inhibited hypocotyl and expanded cotyledons
(C) Preservation of the protective apical hook
(D) Prevention of light-induced chlorophyll synthesis

2015

48. Shade avoidance syndrome is triggered in canopy environments primarily due to:
(A) A highly elevated Red/Far-Red ratio
(B) An increase in blue light intensity
(C) Depletion of carbon dioxide
(D) A significantly decreased Red/Far-Red ratio

2009

49. Which morphological change is a direct characteristic of the shade avoidance syndrome?
(A) Accelerated internode elongation
(B) Thickening of the stem
(C) Enhanced branching
(D) Delayed flowering

2006

50. Photoblastic seeds, such as those of lettuce, require which specific light condition to trigger germination?
(A) High irradiance blue light
(B) A pulse of far-red light
(C) A pulse of red light
(D) Absolute darkness

2025

51. The phenomenon where a far-red light pulse completely cancels the germination-promoting effect of a preceding red light pulse demonstrates:
(A) Standard Pr/Pfr photoreversibility
(B) High irradiance-dependent response
(C) Very low fluence-induced response
(D) Endogenous photoperiodic timing

2011

52. Match the phytochrome response type in List I with its specific characteristic in List II.
List I: (Response Type)
P. Very Low Fluence Response (VLFR)
Q. Low Fluence Response (LFR)
R. High Irradiance Response (HIR)
S. Shade Avoidance Syndrome
List II: (Characteristic)
1. Classic Pr/Pfr photoreversibility
2. Proportional to irradiance time, not photoreversible
3. Triggered by reduced R/FR ratio
4. Saturated at extremely low light, not far-red reversible
(A) P-4, Q-1, R-2, S-3
(B) P-1, Q-4, R-3, S-2
(C) P-4, Q-2, R-1, S-3
(D) P-2, Q-1, R-4, S-3

2009

53. Which phytohormone pathway is fundamentally upregulated to mediate stem elongation during the shade avoidance response?
(A) Abscisic acid biosynthesis
(B) Auxin and Gibberellin biosynthesis
(C) Cytokinin degradation

NODIA

2014

75. A perfectly balanced, intermediate ratio of auxin and cytokinin in tissue culture typically promotes:
(A) Continuous unorganized callus growth
(B) Extensive root elongation
(C) Shoot meristem proliferation
(D) Immediate cell death

2016

76. Select the correct sequence of developmental events during indirect somatic embryogenesis.
(A) Explant → Callus → Proembryogenic masses → Globular embryo → Torpedo embryo
(B) Explant → Torpedo embryo → Globular embryo → Callus
(C) Explant → Proembryogenic masses → Callus → Heart embryo → Globular embryo
(D) Explant → Globular embryo → Callus → Proembryogenic masses → Torpedo embryo

2002

77. Which highly potent synthetic auxin is most universally employed for the induction of somatic embryogenesis in diverse plant species?
(A) Indole-3-acetic acid (IAA)
(B) Indole-3-butyric acid (IBA)
(C) 1-Naphthaleneacetic acid (NAA)
(D) 2,4-Dichlorophenoxyacetic acid (2,4-D)

2008

78. In many somatic embryogenesis protocols, the actual progression and maturation of the embryos require the complete removal or drastic reduction of which hormone?
(A) Cytokinin
(B) Gibberellin
(C) Auxin
(D) Abscisic acid

2019

79. Organogenesis differs fundamentally from somatic embryogenesis because organogenesis involves:
(A) The formation of bipolar structures possessing both root and shoot poles simultaneously.
(B) The unipolar development of shoots or roots with vascular connections to the maternal callus.
(C) The complete bypass of callus formation in all cases.
(D) The exclusive use of haploid tissues.

2025

80. The process by which an explant directly forms shoots or roots without an intervening callus phase is technically termed:
(A) Indirect organogenesis
(B) Indirect embryogenesis
(C) Micrografting
(D) Direct organogenesis

NODIA

2010

81. Which cytokinin is considered naturally occurring and is frequently utilized to induce shoot multiplication in vitro?
(A) Zeatin
(B) Benzyladenine (BAP)
(C) Kinetin
(D) Thidiazuron (TDZ)

2025

82. Consider the following statements regarding hormonal regulation in vitro:
I. TDZ exhibits both cytokinin and auxin-like activity in some tissues.
II. Gibberellic acid is routinely added to strictly inhibit shoot elongation.
III. ABA is often applied to somatic embryos to prevent precocious germination.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I

2013

83. The establishment of a friable callus is critical for initiating cell suspension cultures. Friability is primarily determined by:
(A) Reduced middle lamella adhesion
(B) High levels of lignification
(C) Extensive suberin deposition
(D) Lack of a primary cell wall

2023

84. In a standard batch cell suspension culture, secondary metabolite production typically peaks during which growth phase?
(A) Lag phase
(B) Early exponential phase
(C) Late exponential phase
(D) Stationary phase

2021

85. Tracheary element differentiation from isolated mesophyll cells in vitro, a classic model for cytodifferentiation, is strongly induced by:
(A) Depletion of all hormones

(B) Balancing auxin and cytokinin
(C) Anaerobic conditions
(D) Extreme high temperatures

2021

86. Which distinct morphological feature visually confirms the terminal differentiation of cultured cells into tracheary elements?
(A) Nuclear division without standard cytokinesis
(B) Massive accumulation of starch storage grains
(C) Patterned secondary wall thickenings
(D) Development of mature, functional chloroplasts

2009

87. Cell suspension cultures are often subjected to "elicitation" to purposefully enhance the biosynthesis of:
(A) Primary metabolites like glucose
(B) Structural cellulose
(C) Ribosomal RNA
(D) Bioactive secondary metabolites

2012

88. Habituation in long-term plant tissue cultures refers to the spontaneous phenomenon where cells:
(A) Lose requirement for exogenous growth regulators
(B) Suddenly die despite optimal conditions.
(C) Irreversibly lose all totipotency.
(D) Become strictly dependent on continuous light.

2017

89. Cytological analysis of aging unorganized callus typically reveals a high frequency of which genetic aberration?
(A) Complete loss of the mitochondrial genome
(B) Somaclonal variation (aneuploidy/ polyploidy)
(C) Uniform transition to a heart state
(D) Targeted deletion of marker genes

2007

90. Which physiological parameter must be critically monitored to prevent oxygen starvation in rapidly dividing cell suspension cultures?
(A) Light intensity
(B) Agitation/aeration rate
(C) Agar concentration
(D) Sucrose depletion

2023

91. The structural transition from unorganized callus to a structured meristematic dome marks the onset of:
(A) Histodifferentiation
(B) Plasmolysis
(C) Dedifferentiation
(D) Somatic crossing over

2021

92. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): Meristem tip culture is widely exploited as the most reliable method for eradicating systemic viruses from infected plant clones.
Reason (R): The apical meristem lacks vascular connections and exhibits rapid cell division that outpaces viral replication.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2014

93. In standard micropropagation, the phase focused on maximizing the rapid multiplication of axillary or adventitious shoots is classified as:
(A) Stage I
(B) Stage II
(C) Stage III
(D) Stage IV

2016

94. Which hormone class is typically dominant during the multiplication phase (Stage II) of commercial micropropagation?
(A) Auxins
(B) Gibberellins
(C) Cytokinins
(D) Ethylene

2024

95. The primary objective of Stage III in a standard micropropagation protocol is:
(A) Initial explant establishment and sterilization
(B) In vitro rooting and preparation for soil transfer
(C) Eradication of systemic viruses
(D) Mass proliferation of unorganized callus

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2012

96. Select the correct sequence of procedural stages in a complete micropropagation protocol.
(A) Establishment → Acclimatization → Rooting → Multiplication
(B) Establishment → Multiplication → Rooting → Acclimatization
(C) Multiplication → Establishment → Acclimatization → Rooting
(D) Rooting → Multiplication → Acclimatization → Establishment

2016

97. The physiological condition known as "hyperhydricity" (vitrification) in micropropagated shoots is largely caused by:
(A) High humidity and high cytokinin levels
(B) Excessive exposure to light intensity
(C) Low humidity and agar-based toxicity
(D) Systemic bacterial or fungal infection

2011

98. Nodal segment culture is particularly favored for clonal propagation because it essentially relies on:
(A) Spontaneous mutation
(B) Massive callus production
(C) Pre-existing axillary meristems
(D) Meiotic cell division

2009

99. The critical acclimatization phase (Stage IV) is required because in vitro propagated plantlets typically possess:
(A) Poor cuticles and sluggish stomatal control
(B) Exceptionally thick waxy cuticles
(C) Highly functional and reactive stomata
(D) Overdeveloped root hairs

2010

100. Thermotherapy is often combined with meristem culture to enhance the success rate of:
(A) Callus induction
(B) Secondary metabolite synthesis
(C) Protoplast fusion
(D) Virus elimination

2025

101. Anther culture is practically employed in plant breeding primarily to rapidly generate:
(A) Polyploid varieties
(B) Doubled haploid homozygous lines
(C) Somatic hybrids
(D) Heterozygous synthetic seeds

2013

102. Match the applied tissue culture technique in List I with its principal outcome in List II.
List I: (Technique)
P. Embryo rescue
Q. Anther culture
R. Protoplast fusion
S. Meristem culture
List II: (Principal Outcome)
1. Overcoming post-zygotic incompatibility
2. Production of cybrids
3. Generation of complete homozygosity
4. Virus-free clonal material
(A) P-1, Q-3, R-2, S-4
(B) P-2, Q-4, R-1, S-3
(C) P-4, Q-1, R-3, S-2
(D) P-1, Q-2, R-4, S-3

2016

103. In androgenesis, the targeted cellular pathway must bypass standard gametogenesis so that the microspore instead undergoes:
(A) Degeneration
(B) Meiotic reduction
(C) Fertilization
(D) Sporophytic development

NODIA

2017

104. Colchicine is routinely utilized in doubled haploid production protocols specifically to:
(A) Induce chromosome doubling via spindle inhibition
(B) Induce early flowering
(C) Break down the cell wall
(D) Sterilize the initial explant

2001

105. The process of embryo rescue is most critically required when crossing distantly related species because it directly bypasses:
(A) Pre-zygotic pollen tube arrest
(B) Endosperm failure and embryo abortion
(C) Viral transmission to the progeny
(D) Callus phase organogenesis

2001

106. Enzymatic isolation of viable plant protoplasts generally requires a concentrated mixture of which specific enzymes?
(A) Proteases and lipases
(B) Cellulases and pectinases
(C) Amylases and nucleases
(D) Ligases and restriction endonucleases

2019

107. The chemical most universally applied to chemically induce the fusion of isolated plant protoplasts is:
(A) Polyethylene glycol (PEG)
(B) Sodium hypochlorite
(C) Colchicine
(D) Activated charcoal

2003

108. A somatic hybrid produced via protoplast fusion uniquely contains:
(A) Nuclear genome derived from one parent
(B) Plastid genome derived from one parent
(C) Fused nuclear and cytoplasmic genomes
(D) Absence of any mitochondrial DNA

2001

109. Cytoplasmic hybrids (cybrids) differ from symmetric somatic hybrids in that cybrids inherently possess:
(A) Fused nuclear DNA from both parental lines
(B) Haploid nuclear genome from a single parent
(C) Merged plastid units without a nucleus
(D) Single-parent nucleus with donor-derived cytoplasm

2001

110. Agrobacterium rhizogenes is notoriously utilized in biotechnology to establish which specific type of specialized culture?
(A) Embryogenic cell suspensions
(B) Shoot multiplication cultures
(C) Hairy root cultures
(D) Protoplast cultures

2007

111. Hairy root cultures are particularly valued for the continuous industrial production of secondary metabolites due to their:
(A) Strict requirement for exogenous auxins
(B) Fast growth in hormone-free media
(C) Inability to form any differentiated tissue
(D) Sole reliance on solid media

2011

112. Consider the following statements concerning bioreactor applications in plant cell culture:
I. Bioreactors enable tight control over parameters like pH and dissolved oxygen.
II. Shear stress is a major limitation for plant cells in stirred-tank reactors.
III. Air-lift bioreactors utilize mechanical impellers to maximize aeration.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I

2008

113. Shikonin, a high-value red dye and pharmaceutical, was one of the first secondary metabolites commercially produced using:
(A) Cell suspension cultures of Lithospermum
(B) Hairy root cultures of Catharanthus
(C) Protoplast fusion of Taxus species
(D) Micropropagation of Panax ginseng

2021

114. In two-stage bioreactor cultivation for metabolite production, the first stage optimizes cell mass while the second stage specifically optimizes:
(A) Viral eradication
(B) Chromosome doubling
(C) Product synthesis and accumulation
(D) Shoot regeneration

2009

115. Permeabilization of cultured cells is sometimes applied in industrial bio-production specifically to:
(A) Facilitate the release of intracellular metabolites
(B) Induce cell death and harvest the biomass
(C) Increase resistance to bacterial contamination
(D) Promote rapid protoplast fusion

2019

116. Which strategy involves exposing a cell culture to microbial fragments or heavy metals to rapidly induce secondary metabolite biosynthesis?
(A) Habituation
(B) Vitrification
(C) Cold stratification
(D) Elicitation

2005

117. Forestry applications of tissue culture heavily rely on somatic embryogenesis primarily to achieve:
(A) Immediate fruit production
(B) Clonal propagation of elite timber genotypes
(C) Eradication of soil-borne fungi
(D) Production of rootless scions

2001

118. The immobilization of plant cells in matrices like calcium alginate fundamentally provides which operational advantage?
(A) It permanently halts all cellular metabolism.
(B) It enhances visual monitoring of cell cycle

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progression.
(C) Protection from shear stress during extraction
(D) It accelerates spontaneous mutation rates.

2022

119. The inherent ability of wild-type Agrobacterium tumefaciens to induce crown gall disease relies upon the transfer of which specific DNA segment?
(A) The entire Ti plasmid
(B) The vir gene operon
(C) The main bacterial chromosome
(D) The T-DNA region of the Ti plasmid

2013

120. In the wild-type Ti plasmid, the transferred DNA (T-DNA) is structurally defined by the presence of:
(A) 25-base pair direct repeat border sequences
(B) Promoters and terminators that function only in bacteria
(C) Multiple origins of replication
(D) Antibiotic resistance genes targeting kanamycin

2011

121. The oncogenes (onc) carried within the wild-type T-DNA typically encode enzymes for the biosynthesis of which specific molecules?
(A) Gibberellins and abscisic acid
(B) Auxins and cytokinins
(C) Opines exclusively
(D) Antibiotics

2008

122. Consider the following statements about wild-type Ti and Ri plasmids:
I. Ri plasmids naturally induce hairy roots.
II. Opine synthesis genes are located on the T-DNA.
III. Opine catabolism genes are located outside the T-DNA on the Ti plasmid.
IV. The vir region is integrated into the plant genome along with the T-DNA.
Which of the above statement(s) is/are correct?
(A) I, II and III
(B) II, III and IV
(C) I and IV
(D) I, II and IV

2005

123. Opines, such as octopine and nopaline, function fundamentally as:
(A) Agrobacterium-exclusive carbon and nitrogen sources
(B) Toxins that kill surrounding plant cells
(C) Plant defense molecules against bacterial invasion
(D) Phytohormones that stimulate cell division

2011

124. The virulence (vir) region of the Ti plasmid is essentially composed of genes that encode machinery for:
(A) Fixing atmospheric nitrogen
(B) Replicating the Ti plasmid in E. coli
(C) Processing and transferring the T-DNA
(D) Synthesizing the cellulose bacterial cell wall

2004

125. The specific orientation of T-DNA transfer into the plant cell is fundamentally dictated by:
(A) The orientation of the oncogenes
(B) The left border sequence, which initiates the transfer
(C) The size of the T-DNA region
(D) Initiation at the right border sequence

2019

126. Select the correct sequence of events during T-DNA processing in Agrobacterium.
(A) Acetosyringone perception → VirA/VirG activation → VirD1/D2 nicking → T-strand formation
(B) VirD1/D2 nicking → Acetosyringone perception → VirA/VirG activation → T-strand formation
(C) VirA/VirG activation → Acetosyringone perception → T-strand formation → VirD1/D2 nicking
(D) T-strand formation → VirA/VirG activation → VirD1/D2 nicking → Acetosyringone perception

2019

127. Which component covalently attaches to the 5' end of the single-stranded T-DNA to protect it and guide it to the plant nucleus?
(A) VirE2
(B) VirD2
(C) VirB
(D) VirF

2011

128. Agrobacterium actively recognizes highly susceptible plant cells via sensory perception of which specific class of wound-induced exudates?
(A) Polysaccharides
(B) Glycoproteins
(C) Short-chain fatty acids
(D) Phenolics (e.g., acetosyringone)

NODIA

2022

129. The initial detection of host plant phenolic signals is executed by which Agrobacterium sensory kinase?
(A) VirA
(B) VirG
(C) VirC
(D) VirD1

2003

130. Following perception, the sensory kinase transphosphorylates which response regulator to activate the transcription of all other vir operons?
(A) VirB
(B) VirE2
(C) VirG
(D) VirD2

2013

131. The structural channel spanning the bacterial membranes responsible for exporting the T-complex into the plant cell is primarily constructed by proteins from which vir operon?
(A) virB
(B) virA
(C) virC
(D) virF

2025

132. Consider the following proteins that actively coat the single-stranded T-DNA during its transit through the plant cytoplasm to prevent nucleolytic degradation:
I. VirD2
II. VirE2
III. VirA
IV. VirG
V. RecA
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I, II and IV
(D) I, IV and V

2019

133. The nuclear localization signals (NLS) required to actively transport the T-complex through the plant nuclear pores are located on which proteins?
(A) VirA and VirG
(B) VirD2 and VirE2
(C) VirB1 to VirB11
(D) The plant histones only

2022

134. Integration of the T-DNA into the plant host genome primarily relies on which host cellular mechanism?
(A) Homologous recombination
(B) Transposon excision
(C) Non-Homologous End Joining (NHEJ)
(D) RNA interference

2025

135. Agrobacterium essentially performs trans-kingdom gene transfer. In this context, it functions analogously to a natural:
(A) Bacterial virus (phage)
(B) Plant pathogen transmitting viroids
(C) Fungal endophyte
(D) Engineer delivering a functional DNA cassette

2007

136. The phenomenon where Agrobacterium fails to effectively infect monocots like cereals as efficiently as dicots is largely attributed to:
(A) Insufficient phenolic inducer production
(B) Absence of an active nuclear membrane in monocots
(C) Complete lack of cell wall pores in monocots
(D) Lethal toxic effects of monocot sugars on bacteria

2009

137. The fundamental principle behind designing a "disarmed" Ti plasmid is the specific deletion or mutation of:
(A) The vir genes
(B) The T-DNA oncogene sequences
(C) The T-DNA borders
(D) The origin of replication

2009

138. Engineered plant transformation vectors typically contain a multiple cloning site (MCS). This site must be strictly located:
(A) Between the left and right T-DNA borders
(B) Outside both T-DNA borders
(C) Within the vir operon
(D) Adjacent to the bacterial origin of replication

2024

139. In a standard binary vector system, the vir genes and the engineered T-DNA region are situated:
(A) On two separate plasmids in Agrobacterium
(B) On a single massive plasmid
(C) On the bacterial main chromosome
(D) Fused together into a co-integrate structure

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2017

140. Which significant advantage does the binary vector system offer over the older co-integrate vector system?
(A) Binary vectors rely on homologous recombination in Agrobacterium for assembly.
(B) Binary vectors lack T-DNA borders, increasing transfer efficiency.
(C) Easier pre-manipulation in E. coli
(D) Binary vectors autonomously replicate in the plant cell without integration.

2001

141. The helper plasmid in a binary system provides which crucial components in trans?
(A) The T-DNA borders
(B) The selectable marker for the plant
(C) The right border only
(D) Functional vir gene products

2001

142. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): Co-integrate vectors require a region of DNA homology between the intermediate E. coli vector and the resident disarmed Ti plasmid.
Reason (R): The intermediate vector cannot independently replicate in Agrobacterium and must integrate into the Ti plasmid via homologous recombination to be maintained.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2015

143. Which promoter is most classically and widely utilized in engineered cassettes to drive strong, constitutive expression of transgenes in dicot plants?
(A) Rubisco small subunit (rbcS) promoter
(B) Cauliflower Mosaic Virus (CaMV) 35S promoter
(C) Phaseolin promoter
(D) Patatin promoter

2021

144. To ensure proper mRNA transcript processing, stability, and termination in the plant cell, the engineered gene cassette must include a eukaryotic:
(A) Origin of replication
(B) Shine-Dalgarno sequence
(C) Bacterial promoter
(D) Polyadenylation (poly-A) signal

2010

145. A T-DNA construct containing two distinct genes of interest and a selectable marker is designed. To ensure all are transferred successfully, they must collectively reside:
(A) Between the Right and Left Borders
(B) Only near the Left Border
(C) Completely outside the border regions
(D) Immediately upstream of the vir genes

2010

146. Arrange the typical workflow steps for plant transformation using a binary vector system.
I. Clone gene of interest into binary vector in E. coli
II. Mobilize binary vector into Agrobacterium containing a helper plasmid
III. Co-cultivate Agrobacterium with plant explants
IV. Select transformed plant cells on media containing antibiotics/herbicies
(A) I → II → III → IV
(B) II → I → III → IV
(C) I → III → II → IV
(D) III → I → IV → II

NODIA

2019

147. Selectable marker genes are absolutely essential in plant transformation procedures because they:
(A) Confer a survival advantage to transformed cells
(B) Inhibit the growth of Agrobacterium post-co-cultivation.
(C) Visually color the transformed cells blue.
(D) Induce spontaneous shoot regeneration.

2018

148. The widely used nptII selectable marker gene confers cellular resistance to which specific antibiotic?
(A) Hygromycin
(B) Carbenicillin
(C) Cefotaxime
(D) Kanamycin

2017

149. The biochemical mechanism by which the nptII enzyme provides resistance is by:
(A) Cleaving the beta-lactam ring of the antibiotic
(B) Phosphorylating the antibiotic molecule

2014

171. A major, frequently encountered drawback of particle bombardment compared to Agrobacterium delivery is the high tendency for:
(A) Complex and multicopy integration patterns
(B) Strict limitation to dicot species
(C) Complete destruction of the entire explant
(D) Inability to transfer genes larger than 1 kb

2003

172. Consider the following statements concerning direct gene transfer:
I. PEG-mediated transformation requires the prior enzymatic removal of the cell wall.
II. Electroporation can utilize square wave or exponential decay pulses.
III. Biolistics is totally ineffective for transforming monocots like wheat and maize.
IV. Microinjection delivers DNA visually into a single cell under a microscope.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) II, III and IV
(C) I and III
(D) I, II and III

2011

173. Following a transformation experiment, the primary objective of extracting genomic DNA from surviving plant tissues is to:
(A) Immediately quantify the exact protein expression levels
(B) Visually screen for reporter gene fluorescence
(C) Determine the sequence of the host plant's entire genome
(D) Verify the physical presence of the transgene

2023

174. The cetyltrimethylammonium bromide (CTAB) method is extensively used for plant DNA extraction primarily because CTAB efficiently:
(A) Amplifies specific DNA sequences
(B) Cleaves the DNA at specific restriction sites
(C) Removes plant polysaccharides and polyphenols
(D) Synthesizes complementary DNA from mRNA

2016

175. Polymerase Chain Reaction (PCR) is routinely utilized as the first molecular screen for putative transgenics. What constitutes a "positive" result in a standard PCR screen?
(A) A smear across the entire agarose gel
(B) Amplification of a fragment of expected size
(C) The complete absence of any amplified bands
(D) The visible precipitation of blue dye

2015

176. While standard PCR confirms the presence of the transgene in the genome, Reverse Transcription PCR (RT-PCR) is specifically performed to verify:
(A) The precise copy number of the transgene
(B) The exact chromosomal integration site
(C) The final accumulation level of the translated protein
(D) Transcription of the transgene into mRNA

2015

177. In PCR screening of primary transformants (T0), the amplification of the virG gene is occasionally checked. This serves as a critical control to:
(A) Detecting persistent Agrobacterium contamination
(B) Prove the plant genome is intact
(C) Confirm the integration of the T-DNA
(D) Measure the exact efficiency of the promoter

2012

178. If a putative transgenic plant shows a strong positive band for the nptII gene via standard PCR, one can absolutely conclude that:
(A) The plant is expressing the resistance protein perfectly.
(B) The transgene is integrated into a single, stable locus.
(C) The nptII sequence is present in the sample.
(D) The plant will definitely pass the trait to all progeny.

2011

179. The quality and purity of isolated plant genomic DNA for molecular screening are typically assessed by measuring the absorbance ratio at:
(A) 260 nm / 280 nm
(B) 450 nm / 660 nm
(C) 280 nm / 320 nm
(D) 595 nm / 750 nm

2005

180. To rule out the possibility of a failed PCR reaction due to inhibitors in the plant DNA extract, a positive control amplification is run targeting a/an:
(A) Bacterial antibiotic resistance gene
(B) Empty plasmid vector
(C) Viral promoter sequence
(D) Endogenous housekeeping gene (e.g., Actin)

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(A) Addition of exogenous X-Gluc substrate
(B) Continuous supply of ATP and magnesium
(C) Complete absence of oxygen
(D) Excitation by blue or UV light

2006

161. The Luciferase reporter gene system fundamentally differs from GFP because Luciferase requires:
(A) Exogenous addition of luciferin substrate
(B) Excitation by UV light
(C) Destructive fixation of the plant tissue
(D) Localization exclusively in the chloroplast

2012

162. Consider the following statements concerning reporter genes in plant systems:
I. GFP emits green light spontaneously without an external excitation source.
II. GUS assays often result in an insoluble blue precipitate at the site of enzyme activity.
III. Luciferase assays measure bioluminescence.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I

2012

163. Transient expression analysis utilizing reporter genes is primarily conducted to rapidly verify:
(A) Functionality of a promoter construct
(B) Stable, single-copy integration into the plant genome
(C) Gene transmission to the next generation (T1 progeny)
(D) The absolute elimination of Agrobacterium

2022

164. To prevent false-positive GUS signals caused by residual Agrobacterium in the tissue, modern uidA constructs often contain an intron. This ensures GUS expression occurs strictly in plant cells because:
(A) The intron heavily stabilizes the GUS protein in plants.
(B) Bacteria rapidly degrade intron-containing DNA.
(C) The intron acts as a powerful bacterial repressor.
(D) Bacteria cannot splice eukaryotic introns

2024

165. Biolistics (particle bombardment) represents a vectorless gene transfer method that fundamentally relies on:
(A) Chemical permeabilization of the cell membrane
(B) Propulsion of DNA-coated microprojectiles
(C) High-voltage electrical pulses to create transient pores
(D) Viral capsid encapsulation of the transgene

2025

166. In a standard gene gun protocol, the microprojectiles onto which the plasmid DNA is precipitated are typically composed of:
(A) Iron or Aluminum
(B) Copper or Zinc
(C) Gold or Tungsten
(D) Silicon carbide

2010

167. Which specific reagent is universally used in biolistics to efficiently precipitate and bind the DNA onto the surface of the microparticles?
(A) Polyethylene glycol
(B) Sodium dodecyl sulfate
(C) Ethidium bromide
(D) Calcium chloride and spermidine

2019

168. Electroporation facilitates the direct delivery of foreign DNA into plant cells primarily by:
(A) Generating transient microscopic membrane pores
(B) Actively pumping DNA through established ion channels
(C) Inducing immediate cellular division
(D) Denaturing the cell wall cellulose

2014

169. Electroporation of plant tissues usually yields the highest transformation efficiencies when applied to which specific cellular state?
(A) Intact mature leaves
(B) Isolated wall-less protoplasts
(C) Heavily lignified woody stems
(D) Dormant seeds

2016

170. A distinct advantage of biolistics over standard Agrobacterium-mediated transformation is that biolistics:
(A) Always results in single-copy gene integration.
(B) Enables organelle-level transformation
(C) Strictly targets only the nuclear genome.
(D) Requires virtually no specialized equipment.

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(A) The size of the T-DNA fragment
(B) The secondary structure of the translated protein
(C) Genomic sequences adjacent to the insertion site
(D) The origin of replication of the binary vector

2022

191. Efficacy evaluation of a transgenic Bt-cotton plant typically requires subjecting the plant to a rigorous bioassay specifically using:
(A) High concentrations of glyphosate herbicide
(B) Target insect larvae (e.g., Helicoverpa)
(C) Controlled drought stress
(D) Pathogenic strains of Agrobacterium

2016

192. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): The CP4-EPSPS gene confers exceptional tolerance to glyphosate in transgenic crops.
Reason (R): The CP4-EPSPS enzyme aggressively degrades the glyphosate molecule into harmless byproducts within the plant vacuole.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2011

193. The endogenous plant EPSPS enzyme, which is the primary target inhibited by glyphosate, functions critically in the shikimate pathway to synthesize:
(A) Aromatic amino acids (e.g., Phenylalanine)
(B) Complex carbohydrates
(C) Long-chain fatty acids
(D) Branched-chain amino acids

2017

194. In the regulatory framework governing Genetically Modified Organisms (GMOs), a unique "event" specifically refers to:
(A) Any instance of successful T-DNA transfer
(B) The outbreak of a disease in a transgenic field trial
(C) A specific genomic T-DNA insertion event
(D) The process of harvesting the transgenic seeds

2004

195. Biosafety regulations strictly mandate the evaluation of "substantial equivalence," an assessment designed to determine if:
(A) Compositional equivalence to conventional crops
(B) The GMO yields exactly the same tonnage per hectare as the non-GMO.
(C) The transgenic protein is completely identical to a known human protein.
(D) The GM crop uses the exact same amount of water.

2005

196. The mandatory "refuge" strategy implemented alongside the cultivation of commercial Bt crops is biologically designed to:
(A) Provide a habitat for beneficial predatory insects
(B) Increase the overall yield of the Bt crop
(C) Prevent the flow of transgenes into wild relatives
(D) Delay evolved Bt-resistance in target pests

2022

197. To thoroughly evaluate the potential allergenicity of a newly introduced transgenic protein, regulatory bodies frequently require an assessment of the protein's:
(A) Optimal temperature for enzymatic function
(B) Stability in simulated gastric fluid
(C) Ability to bind to plant cell wall components
(D) Maximum absorbance wavelength in a spectrophotometer

2004

198. Gene flow evaluation is a crucial biosafety parameter that actively studies the risk of the transgene:
(A) Moving from the chloroplast to the nucleus
(B) Being ingested and integrated into the human genome
(C) Escaping to non-GM crops or wild relatives
(D) Being completely silenced in subsequent generations

2025

199. A stacking event in transgenic crop terminology occurs when:
(A) A transgene integrates strictly in a tandem repeat configuration.
(B) Protoplasts are stacked together in a fusion chamber.
(C) Transgenic seeds are stored together in a seed bank.
(D) Combining multiple transgenes in one

NODIA

2015

181. A critical limitation of basic end-point PCR for screening primary transformants is that it inherently cannot reliably determine:
(A) The presence or absence of the transgene sequence
(B) Transgene copy number and integration pattern
(C) The size of the amplified fragment
(D) Whether specific primers successfully bound

2022

182. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): Southern blotting remains the gold standard technique for conclusively determining the exact number of transgene integration loci in a genetically modified plant.
Reason (R): Southern blotting utilizes specific restriction enzyme digestion followed by hybridization with a labeled probe to reveal uniquely sized DNA fragments corresponding to individual integration events.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2018

183. In a Southern blot experiment designed to determine transgene copy number, the genomic DNA must be digested with a restriction enzyme that strictly cuts the T-DNA construct:
(A) Multiple times, fragmenting the probe sequence
(B) Only outside the T-DNA borders in the plant genome
(C) Nowhere at all
(D) Once within T-DNA, outside the probe region

2012

184. During the Southern blotting procedure, after restriction digestion and gel electrophoresis, the DNA fragments must be structurally altered to allow probe binding. This step involves:
(A) Alkaline denaturation into single strands
(B) Polymerization
(C) Ligation
(D) Digestion with exonucleases

2006

185. The transfer of DNA from an agarose gel to a solid nitrocellulose or nylon membrane during Southern blotting is classically driven by:
(A) Centrifugation
(B) Capillary action or electrophoretic transfer
(C) Vacuum evaporation
(D) Chemical precipitation

2017

186. In modern molecular analysis, which technique has largely supplemented, and in high-throughput settings replaced, Southern blotting for rapidly estimating transgene copy number?
(A) qPCR
(B) Northern blotting
(C) Western blotting
(D) Standard end-point RT-PCR

2023

187. Transgene silencing is a frequent issue in plants containing multiple, complex copies of a transgene. Which specific molecular mechanism is primarily responsible for post-transcriptional gene silencing (PTGS)?
(A) Double-stranded RNA-mediated mRNA degradation
(B) Excessive DNA methylation of the promoter
(C) Physical deletion of the transgene sequence
(D) Incomplete RNA splicing

2019

188. If a transgenic line contains exactly one single copy of the inserted transgene (hemizygous), Mendelian segregation in the T1 progeny generation upon self-pollination should theoretically yield a phenotypic ratio of:
(A) 1:1
(B) All tolerant
(C) 3:1 (tolerant to susceptible)
(D) 15:1

2015

189. To confirm the stable integration and functional expression of a transgenic protein (e.g., Bt toxin) in the target tissues, which highly specific analytical technique is universally employed?
(A) Southern blotting
(B) PCR of the T-DNA left border
(C) Northern blotting
(D) Western blotting or ELISA

2023

190. Flanking sequence analysis (e.g., via TAIL-PCR) is performed on a commercial transgenic line strictly to determine:

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(C) Pumping the antibiotic out of the cell
(D) Mutating the ribosomal target site

2002

150. The hpt gene is a highly effective selectable marker that fundamentally detoxifies:
(A) Phosphinothricin
(B) Glyphosate
(C) Hygromycin B
(D) Spectinomycin

2004

151. The herbicide-resistance marker gene bar, originally isolated from Streptomyces hygroscopicus, detoxifies which potent herbicidal compound?
(A) Glyphosate
(B) Atrazine
(C) 2,4-D
(D) Glufosinate

2006

152. Match the selectable marker gene in List I with its corresponding selective agent in List II.
List I: (Selectable Marker Gene)
P. bar
Q. hpt
R. nptII
S. cp4-epsps
List II: (Selective Agent)
1. Glyphosate
2. Kanamycin
3. Glufosinate
4. Hygromycin
(A) P-3, Q-4, R-2, S-1
(B) P-1, Q-2, R-3, S-4
(C) P-3, Q-1, R-4, S-2
(D) P-2, Q-3, R-1, S-4

2012

153. A positive selectable marker system, unlike antibiotic resistance, allows transformed cells to survive by:
(A) Killing non-transformed cells with toxins
(B) Enabling utilization of novel carbon sources
(C) Creating visual fluorescence
(D) Preventing viral replication

2010

154. Following co-cultivation, antibiotics like cefotaxime or timentin are routinely added to the plant tissue culture medium specifically to:
(A) Select for plant cells containing the T-DNA
(B) Eradicate contaminating Agrobacterium
(C) Induce the vir genes
(D) Promote root elongation

2010

155. Why is kanamycin generally considered an ineffective selective agent for many gramineous (cereal) species?
(A) High inherent tolerance to the antibiotic
(B) Cereal cells naturally express high levels of the nptII enzyme.
(C) Kanamycin is instantly degraded by cereal cell wall peroxidases.
(D) The T-DNA cannot enter cereal cells in the presence of kanamycin.

2011

156. Scorable markers (reporter genes) differ critically from selectable markers because reporter genes fundamentally:
(A) Provide a lethal mechanism to eliminate non-transgenics.
(B) Confer resistance to lethal chemical agents.
(C) Allow spatial localization of gene expression
(D) Must be driven by a tissue-specific promoter only.

2024

157. The classical uidA (GUS) reporter gene system encodes the enzyme beta-glucuronidase, which visibly turns tissues:
(A) Red when supplied with luciferin
(B) Green under UV illumination
(C) Yellow in the presence of mannose
(D) Blue with X-Gluc substrate

2008

158. A major technical limitation of the standard histochemical GUS assay is that:
(A) The enzyme degrades extremely rapidly in plant cells.
(B) It cannot be used with the 35S promoter.
(C) It requires the destruction of the tissue being analyzed.
(D) It requires sophisticated fluorescent microscopes to visualize.

2010

159. Which scorable marker is most perfectly suited for continuous, non-destructive, real-time tracking of gene expression in living plant tissues?
(A) GUS (uidA)
(B) Green Fluorescent Protein (GFP)
(C) Neomycin phosphotransferase (nptII)
(D) Beta-galactosidase (lacZ)

2009

160. The functional activation and fluorescence of GFP in transformed plant cells primarily requires:

NODIA

variety

2011

200. When screening for the precise event identity of a commercial GMO shipment, analytical laboratories usually rely heavily on:
(A) Primers targeting the T-DNA/genomic junction
(B) Simple phenotypic observation of leaf shape
(C) Endogenous EPSPS enzyme activity assays
(D) Visually scoring the seedlings for antibiotic resistance

2003

201. The targeted induction of Double-Strand Breaks (DSBs) is the fundamental initiating step for modern genome editing. In plants, the dominant natural repair pathway for these DSBs often introduces small errors. This pathway is called:
(A) Homology-Directed Repair (HDR)
(B) Non-Homologous End Joining (NHEJ)
(C) Nucleotide Excision Repair (NER)
(D) Mismatch Repair (MMR)

2016

202. Match the specific DNA repair pathway in List I with its characteristic outcome during targeted genome editing in List II.
List I: (DNA Repair Pathway)
P. NHEJ without a repair template
Q. HDR with a homologous donor template
R. Microhomology-Mediated End Joining (MMEJ)
S. Base Excision Repair
List II: (Characteristic Outcome)
1. Small, unpredictable insertions or deletions (indels) causing knockouts
2. Precise, predefined sequence replacement or gene knock-in
3. Single nucleotide modification without a DSB
4. Frequent small deletions flanked by short microhomologies
(A) P-1, Q-2, R-4, S-3
(B) P-2, Q-1, R-3, S-4
(C) P-1, Q-3, R-2, S-4
(D) P-4, Q-2, R-1, S-3

2009

203. For a researcher intending to entirely "knock out" or disrupt the function of a specific susceptibility gene in a crop plant, which cellular repair mechanism do they primarily rely upon following CRISPR cleavage?
(A) Error-prone Non-Homologous End Joining
(B) Perfect Homology-Directed Repair
(C) Photoreactivation
(D) Base editing

2012

204. Why is Homology-Directed Repair (HDR) considered technically highly challenging and inefficient to achieve in higher plants compared to NHEJ?
(A) HDR pathways naturally function exclusively in the mitochondria.
(B) Plants entirely lack the necessary enzymes to process homologous templates.
(C) HDR is active mainly in S/G2 cell cycle phases
(D) HDR inherently requires a continuous supply of light.

2021

205. The specific outcome of an NHEJ event that occurs in the precise middle of a critical coding exon is most likely to be:
(A) A silent mutation with zero effect
(B) A perfectly functional, albeit larger, protein
(C) Complete replication of the entire chromosome
(D) Frameshift leading to premature stop codons

2004

206. Which engineered nuclease utilizes specific arrays of amino acid modules, where each single module rigorously recognizes and binds exactly one corresponding nucleotide in the target DNA?
(A) CRISPR/Cas9
(B) Zinc Finger Nucleases (ZFNs)
(C) TALENs
(D) Meganucleases

2022

207. Both ZFNs and TALENs require the use of an attached endonuclease domain to actually cleave the DNA strand. This specific domain is derived almost exclusively from which natural restriction enzyme?
(A) EcoRI
(B) FokI
(C) HindIII
(D) BamHI

2015

208. The cleavage activity of the FokI endonuclease domain utilized in ZFNs and TALENs strictly requires the protein to undergo:
(A) Phosphorylation
(B) Ubiquitination
(C) Glycosylation

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29. (D) Phytochromobilin
The light-sensing capability of phytochrome depends on a covalently attached linear tetrapyrrole chromophore called phytochromobilin. This molecule is synthesized within plastids and then exported to the cytoplasm, where it binds to the phytochrome apoprotein. Phytochromobilin undergoes a conformational change upon light absorption, which triggers the conversion between the inactive Pr form and the biologically active Pfr form of the photoreceptor.

30. (C) Cysteine
In the phytochrome molecule, the phytochromobilin chromophore is covalently linked to the apoprotein via a thioether bond. This linkage occurs specifically at a conserved cysteine residue located in the N-terminal domain of the protein. This stable attachment is essential for the chromophore to accurately perceive light and transmit the signal through conformational changes to the rest of the protein.

31. (B) A cis-to-trans isomerization of the chromophore
When the Pr form of phytochrome absorbs red light, the phytochromobilin chromophore undergoes a cis-to-trans isomerization at the C15-C16 double bond. This chemical change induces a wider conformational shift in the surrounding protein structure, converting it into the biologically active Pfr form. This transformation is the fundamental molecular event that initiates the light signaling cascade within the plant cell.

32. (C) III only
Phytochromes are complex proteins where the N-terminus handles light perception and the C-terminus manages dimerization and signaling. While Pfr is generally the active form and Pr absorbs maximally at 660 nm, the statement regarding chromophore synthesis is incorrect. Phytochromobilin is synthesized within the plastids, not the cytoplasm, before being assembled with the apoprotein to form the functional photoreceptor.

33. (A) Plastid
The biosynthesis of phytochromobilin, the light-absorbing chromophore of phytochrome, begins in the plastids. It is derived from heme through a series of enzymatic steps. After its synthesis, the chromophore is transported into the cytosol, where it spontaneously attaches to the phytochrome apoprotein. This compartmentalization reflects the complex metabolic coordination required for the assembly of functional plant photoreceptor systems.

34. (C) PhyA
Phytochrome A is classified as a Type I phytochrome because it is highly light-labile. In etiolated seedlings, PhyA accumulates to high levels in the inactive Pr form, but upon exposure to light, the active Pfr form is rapidly degraded by the proteasome. This instability makes PhyA particularly sensitive to low light levels and transient pulses, distinguishing it from the light-stable Type II phytochromes.

35. (C) 730 nm
The Pfr form of phytochrome is the physiologically active state and exhibits an absorption maximum in the far-red region of the spectrum, typically around 730 nm. When Pfr absorbs far-red light, it is converted back into the inactive Pr form, which absorbs red light at 660 nm. This photoreversible property is the basis for phytochrome-mediated light sensing and response regulation.

36. (D) Pfr spontaneously reverts to Pr independent of light.
Dark reversion is a light-independent process in which the biologically active Pfr form of phytochrome slowly reverts to the inactive Pr form in the dark. This spontaneous conversion acts as a metabolic timer, allowing plants to sense the duration of the dark period. The rate of dark reversion varies among different phytochrome members, influencing how long a light-induced signal persists.

37. (B) Nucleus
Upon activation by red light, the phytochrome molecule undergoes a conformational change to the Pfr form, which then translocates from the cytoplasm into the nucleus. Once inside the nucleus, Pfr interacts with various transcription factors and signaling proteins to regulate gene expression. This nuclear translocation is a critical step in the signal transduction pathway that leads to photomorphogenesis and other light-induced responses.

NODIA

2010

217. A critical potential drawback associated with CRISPR/Cas9 applications in complex plant genomes is "off-target" effects. These occur precisely when:
(A) The Cas9 protein fails to translate correctly.
(B) The sgRNA guides cleavage at unintended similar loci
(C) The target gene expresses too much protein.
(D) The plant entirely degrades the sgRNA.

2019

218. Modern base editors represent an advanced, highly specific adaptation of the CRISPR system. A Cytosine Base Editor (CBE) primarily functions by:
(A) Fusing dCas9 to a cytidine deaminase (C to T)
(B) Creating massive chromosomal deletions
(C) Transporting a massive donor template to the site
(D) Cutting the DNA and allowing random NHEJ to insert a Cytosine

2017

219. To create a completely transgene-free genome-edited crop variety (essential for circumventing stringent GMO regulations in some jurisdictions), researchers frequently employ which highly effective strategy?
(A) Segregating Cas9 cassettes through sexual crossing
(B) Integrating the Cas9 gene into the plastid genome
(C) Performing standard Agrobacterium transformation and keeping the plants continuously in tissue culture
(D) Using purely physical methods to mask the presence of the transgene

2022

220. While standard Cas9 produces blunt ends, an alternative CRISPR nuclease widely utilized in plant biotechnology naturally creates a highly advantageous 5-nucleotide staggered cut (sticky ends). What is the name of this specific enzyme?
(A) dCas9
(B) EcoRI
(C) Cas12a (Cpf1)
(D) Cas13

2022

221. Which fundamental property of the Cas12a nuclease makes it exceptionally well-suited for targeting AT-rich genomic regions such as plant promoters?
(A) It does not require any PAM sequence whatsoever.
(B) It only binds to single-stranded RNA.
(C) It actively converts AT pairs into GC pairs.
(D) Recognition of specific T-rich PAM sequences

2017

222. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): Multiplex genome editing, simultaneously targeting several different genes, is vastly simpler to engineer using CRISPR/Cas9 than using ZFNs or TALENs.
Reason (R): For multiplexing with CRISPR/Cas9, one simply needs to express multiple small sgRNAs alongside a single Cas9 protein, whereas ZFNs or TALENs require engineering completely new, massive binding proteins for every single target.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2004

223. When evaluating the final molecular profile of a CRISPR/Cas9 edited plant intended for commercial agricultural release, it is absolutely paramount to verify the complete absence of:
(A) Native plant transcription factors
(B) Vector backbone and Cas9 transgene sequences
(C) Intact endogenous EPSPS sequences
(D) Naturally occurring chloroplast DNA

2005

224. Prime Editing is an exceptionally advanced CRISPR technology uniquely capable of:
(A) Instantly generating haploid plants
(B) Eradicating all plant viruses simultaneously
(C) Rapidly synthesizing artificial chromosomes
(D) Precise base conversions and small indels

2005

225. In the sophisticated Prime Editing complex, the engineered pegRNA (prime editing guide RNA) fundamentally serves dual roles:
(A) Guiding complex and providing RT templates
(B) Guiding the complex and inhibiting cell division
(C) Providing the Cas9 protein and degrading

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maintaining the overall mechanical integrity and shape of the cell.

10. (B) Tip growth
Root hairs exhibit a highly polarized growth mechanism known as tip growth, where new cell wall material is added exclusively at the apical dome. This process involves intense localized vesicle secretion and specialized cytoskeletal organization. Unlike diffuse growth, which occurs across the cell surface, tip growth allows cells to extend rapidly through the soil to maximize nutrient and water absorption.

11. (A) Secretory vesicles
In rapidly growing pollen tubes, the extreme apex contains a region known as the clear zone. This area is devoid of large organelles and is instead densely packed with secretory vesicles delivered by the actin-myosin system. These vesicles provide the essential proteins and polysaccharides needed for continuous cell wall expansion and membrane growth at the advancing tip of the tube.

12. (B) I and III
Tip growth in plant cells is characterized by a highly dynamic actin cytoskeleton that facilitates the transport of secretory vesicles to the apex. Simultaneously, a steep tip-focused calcium gradient is maintained, with the highest concentration found at the extreme apical dome. While microtubules are present, they are not the primary drivers of vesicle transport in this specific polarized growth region.

13. (D) Calcium gradient
A steep, tip-focused gradient of cytosolic calcium ions is essential for maintaining the polarity of growing pollen tubes. This gradient regulates the activity of proteins involved in vesicle fusion and actin cytoskeleton dynamics at the apex. Disrupting this calcium signal leads to the immediate cessation of growth and a loss of directional control, highlighting its role in apical dominance.

14. (C) Global surface-level expansion
Diffuse growth is characterized by the expansion of the cell wall across its entire surface area rather than at a single localized point. This process involves the coordinated loosening of the existing wall and the deposition of new material throughout the cell cortex. In contrast, tip growth is strictly limited to the apical region, resulting in highly elongated, filamentous cell structures.

15. (B) Apex-restricted wall loosening
Cells undergoing tip growth maintain their polarity by restricting cell wall loosening and expansion to the extreme apical dome. This localized softening allows internal turgor pressure to drive growth specifically at the tip while the rest of the cell remains rigid. This mechanism ensures the maintenance of a narrow, elongated shape, which is vital for structures like root hairs.

16. (D) Cortical microtubules and cellulose microfibrils
Cell expansion in the root elongation zone is primarily controlled by the interaction between cortical microtubules and cellulose microfibrils. The microtubules guide the orientation of newly synthesized microfibrils, which act as structural hoops around the cell. This arrangement allows for longitudinal expansion driven by turgor pressure while preventing lateral swelling, ensuring the root grows deeper into the soil profile.

17. (A) Actin-myosin directed vesicular trafficking
The rapid extension of root hairs requires the continuous delivery of cell wall components to the growing tip. This process is mediated by the actin cytoskeleton and myosin motor proteins, which actively transport secretory vesicles toward the apex. This targeted trafficking system ensures that building materials are concentrated precisely where expansion occurs, supporting the highly polarized nature of tip growth.

18. (C) Light direction dictates the site of rhizoid outgrowth.
In the zygotes of the brown alga Fucus, cellular polarity is established by external environmental cues rather than being strictly predetermined. Unidirectional light is a primary signal that determines the developmental axis, with the rhizoid always emerging from the shaded side of the cell. This response involves the localized accumulation of calcium ions and the reorganization of the actin cytoskeleton.

NODIA

19. (A) Cyclin-dependent kinases (CDKs)
The plant cell cycle is regulated by the sequential activation and inactivation of cyclin-dependent kinases. These enzymes form complexes with

ANSWERS

1. (A) Preprophase band
The preprophase band is a dense ring of microtubules and actin filaments that forms just before mitosis in plant cells. It accurately marks the future plane of cytokinesis by defining where the cell plate will eventually fuse with the parental cell wall. This temporary structure disappears before the mitotic spindle fully develops during the prophase stage of division.

2. (C) Cellulose-guided turgor pressure
Turgor pressure provides the mechanical force required to stretch the cell wall during the expansion phase. The orientation of cellulose microfibrils within the wall constrains this expansion, directing it along a specific axis. This interaction between internal hydraulic pressure and structured wall reinforcement allows plant cells to achieve significant elongation and reach their final functional dimensions during development.

3. (A) Microtubules and actin filaments
During cytokinesis, the phragmoplast serves as a scaffold for cell plate assembly. It is primarily composed of two sets of opposing microtubules and actin filaments that guide Golgi-derived vesicles to the division plane. These cytoskeletal elements facilitate the transport and fusion of vesicles, ensuring the proper construction of the new cell wall between the two daughter nuclei.

4. (D) Expansin
According to the acid growth hypothesis, auxin induces the acidification of the apoplast by activating proton pumps. This decrease in pH activates expansins, which are non-enzymatic proteins that loosen the hydrogen bonds between cellulose microfibrils and cross-linking glycans. This temporary wall relaxation allows turgor pressure to drive cell expansion, facilitating the rapid elongation observed in various plant tissues.

5. (C) G2 phase
The preprophase band is a transient cytoskeletal structure that appears specifically during the G2 phase of the plant cell cycle. It forms a cortical ring of microtubules that predicts the future site of the division plane. Once the cell enters prophase and the spindle apparatus begins to form, the preprophase band is disassembled, leaving a molecular memory.

6. (C) They are randomly oriented in elongating cells.
During diffuse growth, cellulose microfibrils are typically deposited in a highly organized, transverse orientation perpendicular to the axis of elongation. This specific arrangement is guided by cortical microtubules and functions to restrict lateral expansion while allowing for longitudinal stretching. Random orientation would prevent controlled, directional growth, which is essential for the proper development of roots, stems, and other organs.

7. (D) Golgi apparatus
The Golgi apparatus plays a central role in plant cytokinesis by producing secretory vesicles filled with cell wall precursors and polysaccharides. These vesicles are transported along the phragmoplast to the center of the dividing cell. Upon fusion, they form the early cell plate, which eventually expands outward to meet the parental cell wall and complete the division process.

8. (A) Cell expansion
Secondary cell walls provide structural support and are deposited only after a cell has reached its final size and stopped expanding. This timing is critical because the lignin and thick cellulose layers characteristic of secondary walls are rigid and would prevent further growth. Once expansion is complete, the cell focuses on reinforcing its structure for specialized functional roles.

9. (B) Cortical microtubules - align cellulose deposition
Cortical microtubules act as templates for the synthesis and arrangement of cellulose microfibrils in the plant cell wall. Cellulose synthase complexes move along these microtubule tracks, ensuring that the microfibrils are deposited in a specific orientation. This alignment is fundamental to controlling the direction of cell expansion and

NODIA

(D) Dimerization

2016

209. To successfully generate a complete double-strand break using TALEN architecture, a researcher must design and deliver:
(A) Opposing TALEN pairs with optimal spacing
(B) A single TALEN protein targeting one specific sequence
(C) A TALEN protein complexed with a guide RNA
(D) Four identical TALEN proteins

2022

210. A significant inherent difficulty in designing ZFNs compared to TALENs or CRISPR is that in ZFNs:
(A) The recognition domains must be paired with an RNA molecule.
(B) Zinc fingers only recognize AT-rich regions.
(C) Context-dependent module interaction affects binding
(D) ZFNs cannot function in plant cells.

2016

211. The revolutionary genome editing system CRISPR/Cas9 fundamentally relies on an RNA-guided mechanism. This specific mechanism originally evolved in nature as a:
(A) Bacterial adaptive immune system against phages
(B) Plant viral replication strategy
(C) Fungal mechanism for degrading lignin
(D) Mammalian antibody generation system

2012

212. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A): In the CRISPR/Cas9 system, the single guide RNA (sgRNA) complex completely dictates the exact genomic sequence to be cleaved.
Reason (R): The Cas9 protein inherently lacks any natural sequence-specific DNA-binding domains of its own and acts solely as an endonuclease guided by RNA-DNA base pairing.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2004

213. For the widely utilized Streptococcus pyogenes Cas9 (SpCas9) to successfully cleave target DNA, the 20-nucleotide target sequence MUST be immediately followed by a specific Protospacer Adjacent Motif (PAM). What is the standard sequence of this specific PAM?
(A) 5'-TTTV-3'
(B) 5'-NGG-3'
(C) 5'-NNNNGATT-3'
(D) 5'-CCG-3'

2005

214. The structural architecture of an engineered single guide RNA (sgRNA) represents a synthetic fusion of which two naturally occurring CRISPR RNA components?
(A) mRNA and tRNA
(B) siRNA and miRNA
(C) crRNA and tracrRNA
(D) snRNA and snoRNA

2002

215. Upon locating the correct target sequence adjacent to a PAM, the Cas9 enzyme utilizes two distinct catalytic domains (RuvC and HNH) to execute which specific action?
(A) Creating a staggered single-strand nick
(B) Excising a massive 100 bp fragment
(C) Phosphorylating the adjacent histones
(D) Generating blunt DSBs upstream of the PAM

2002

216. Match the genome editing component in List I with its functional property in List II.
List I: (Genome Editing Component)
P. Cas9 RuvC domain
Q. sgRNA spacer sequence
R. PAM sequence
S. FokI domain
List II: (Functional Property)
1. Determines exact binding specificity through Watson-Crick pairing
2. Mandatory short DNA motif strictly required for Cas9 binding
3. Cleaves the non-target DNA strand in the CRISPR complex
4. Cleaves DNA only upon successful dimerization in TALENs
(A) P-3, Q-1, R-2, S-4
(B) P-1, Q-2, R-3, S-4
(C) P-3, Q-2, R-1, S-4
(D) P-4, Q-1, R-2, S-3

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regulatory proteins called cyclins, which dictate their substrate specificity and timing. By phosphorylating key target proteins, CDKs drive the progression of the cell through G1, S, G2, and M phases, ensuring that DNA replication and division occur correctly.

20. (D) Retinoblastoma-related (RBR) proteins
Progression from the G1 phase to the S phase in plants requires the inactivation of Retinoblastoma-related proteins. These proteins normally bind to and inhibit E2F transcription factors, which are necessary for the expression of S-phase genes. Upon phosphorylation by D-type cyclin-CDK complexes, RBR releases E2F, allowing the cell to initiate DNA replication and continue through the cell cycle.

21. (B) Cytokinin
Cytokinins are major plant hormones that promote cell division by inducing the expression of D-type cyclins. These cyclins associate with CDKs to trigger the transition from the G1 phase to the S phase. By upregulating CYCD expression, cytokinins effectively push quiescent cells back into the active cell cycle, playing a critical role in meristem activity and overall plant growth.

22. (A) I, II and III
Plant cell cycle regulation involves CDKA, which functions across various phases, and B-type CDKs, which are plant-specific and critical for the G2 to M transition. Endoreduplication is a specialized process where cells undergo multiple rounds of DNA replication without entering mitosis or cytokinesis. Conversely, KRPs act as inhibitors that decrease CDK activity, contrary to the idea of enhancement.

23. (D) Polyploidy
Endoreduplication is a modified cell cycle where the cell replicates its genomic DNA without subsequent mitosis or cytokinesis. This results in the accumulation of multiple sets of chromosomes within a single nucleus, leading to polyploidy. This process is common in specialized tissues, such as the endosperm or trichomes, where increased nuclear content supports high metabolic activity and large cell size.

24. (A) Induction of CDK inhibitors
Abscisic acid is a stress-related hormone that typically inhibits cell division to conserve energy and resources. It exerts this effect by inducing the expression of cyclin-dependent kinase inhibitors, such as KRPs. These inhibitors bind to CDK complexes and block their activity, leading to cell cycle arrest in the G1 phase and allowing the plant to better withstand unfavorable environmental conditions.

25. (B) A-type and B-type cyclins
The transition from the G2 phase into mitosis is regulated by CDKA in association with both A-type and B-type cyclins. These complexes phosphorylate various substrates necessary for spindle formation, nuclear envelope breakdown, and chromosome condensation. While B-type cyclins are particularly critical for the M-phase entry, A-type cyclins also play a significant role in coordinating the late stages of the G2 phase.

NODIA

26. (B) RBR phosphorylation → E2F activation → S-phase gene transcription
The initiation of the S phase follows a precise regulatory sequence beginning with the phosphorylation of Retinoblastoma-related proteins by CDK complexes. This phosphorylation causes RBR to release the E2F transcription factor, which had been held in an inactive state. Once liberated, E2F activates the transcription of genes required for DNA synthesis, effectively triggering the transition into the S phase.

27. (A) Anaphase-promoting complex (APC/C)
The exit from mitosis requires the rapid degradation of mitotic cyclins, which is carried out by the anaphase-promoting complex. This large multisubunit E3 ubiquitin ligase targets cyclins for destruction by the 26S proteasome. The resulting drop in CDK activity is essential for the completion of cytokinesis and the transition of the daughter cells into the subsequent G1 phase.

28. (C) Red and far-red
Phytochromes are specialized photoreceptors in plants that primarily detect red and far-red wavelengths of light. They exist in two interconvertible forms, Pr and Pfr, which absorb light at different peaks. This ability to sense the ratio of red to far-red light allows plants to monitor their light environment, regulating processes such as seed germination, stem elongation, and flowering.

47. (B) Inhibited hypocotyl and expanded cotyledons
Photomorphogenesis is the developmental program initiated when etiolated seedlings first encounter light. This process is characterized by a significant reduction in the rate of hypocotyl elongation and the simultaneous expansion and greening of the cotyledons. These changes prepare the plant for autotrophic growth by optimizing its surface area for light capture and stabilizing its structure for exposure to the environment.

48. (D) A significantly decreased Red/Far-Red ratio
Plants growing under a dense canopy experience a light environment depleted in red wavelengths, which are absorbed by chlorophyll, but enriched in far-red light. This result in a significantly decreased Red/Far-Red ratio, which is sensed by phytochromes. This low ratio triggers the shade avoidance syndrome, a set of morphological changes designed to help the plant outcompete neighbors for available light.

49. (A) Accelerated internode elongation
The shade avoidance syndrome is a competitive response characterized by the rapid elongation of internodes and petioles. By accelerating vertical growth, the plant attempts to reach the top of the canopy and access unfiltered sunlight. Other features of this syndrome include reduced branching and earlier flowering, all directed toward ensuring reproductive success in a light-limited and competitive environment.

50. (C) A pulse of red light
Photoblastic seeds, such as those of lettuce, require a light stimulus to break dormancy and initiate germination. This response is primarily triggered by a short pulse of red light, which converts inactive Pr into the active Pfr form of phytochrome. The presence of Pfr signaling is the critical internal cue that informs the seed it is near the soil surface and receives sufficient light.

51. (A) Standard Pr/Pfr photoreversibility
The classic experiment showing that far-red light can cancel the effect of red light on lettuce seed germination demonstrates Pr/Pfr photoreversibility. This occurs because red light converts Pr to the active Pfr form, while far-red light instantly converts Pfr back to the inactive Pr form. The final physiological response of the seed is determined by the last wavelength of light it receives.

52. (A) P-4, Q-1, R-2, S-3
Phytochrome responses are categorized by their light requirements and reversibility. The Very Low Fluence Response is extremely sensitive and non-reversible. The Low Fluence Response follows the classic photoreversibility rule. The High Irradiance Response depends on continuous exposure and irradiance time. Finally, the shade avoidance syndrome is a specific adaptive response triggered by the detection of a reduced Red/Far-Red ratio in the environment.

53. (B) Auxin and Gibberellin biosynthesis
To achieve the rapid stem elongation seen in shade avoidance, plants upregulate the biosynthesis and transport of auxin and gibberellins. These hormones work together to promote cell wall loosening and expansion in the internodes. The increase in these growth-promoting hormones is a direct result of the low R/FR ratio perceived by phytochromes, which alters the activity of transcription factors like PIFs.

54. (C) Ethylene
In etiolated seedlings, the apical hook is maintained by an asymmetric distribution of auxin, which is heavily influenced by the presence of ethylene. Ethylene acts as a key signal that prevents the hook from opening, thereby protecting the delicate shoot apical meristem as it pushes through the soil. Upon exposure to light, phytochrome signaling reduces ethylene production, leading to hook opening.

55. (D) Germination occurs near the surface in adequate light.
Small-seeded plants have limited nutrient reserves and must begin photosynthesis quickly after germination. Phytochrome serves as a light sensor to ensure that these seeds only germinate when they are close enough to the soil surface to receive light. By preventing germination in deep soil or under dense shade, the plant increases the chances of seedling survival and successful autotrophic establishment.

56. (A) Totipotency
Totipotency is the unique biological property of a single plant cell that enables it to regenerate an entire, fertile adult organism. This capacity implies that the cell retains all the genetic information and functional potential required for every stage of development. Unlike animal cells, many modified plant cells can revert to an

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38. (C) Negative regulators of light signaling
Phytochrome Interacting Factors are a group of basic helix-loop-helix transcription factors that primarily function as negative regulators of light signaling. In the dark, PIFs accumulate and promote skotomorphogenesis by repressing light-induced genes and promoting hypocotyl elongation. When plants are exposed to light, active phytochrome interacts with PIFs, leading to their degradation and allowing photomorphogenesis to proceed.

39. (D) Targeting positive regulators for degradation
In the dark, the COP1/SPA complex acts as an E3 ubiquitin ligase that targets positive regulators of photomorphogenesis, such as HY5, for degradation by the 26S proteasome. This mechanism prevents the expression of light-induced genes, thereby maintaining the etiolated state of the seedling. By actively destroying these key transcription factors, the complex ensures that skotomorphogenesis occurs in the absence of light.

40. (A) Phosphorylation and degradation of PIFs
When the active Pfr form of phytochrome enters the nucleus, it directly binds to Phytochrome Interacting Factors. This interaction triggers the rapid phosphorylation of PIF proteins by various kinases, which then marks them for degradation via the ubiquitin-proteasome pathway. The removal of these negative regulators allows the plant to switch from skotomorphogenesis to photomorphogenesis, initiating leaf expansion and chlorophyll synthesis.

41. (B) HY5
HY5 is a key bZIP transcription factor that promotes photomorphogenesis by activating a wide range of light-responsive genes. In the dark, it is degraded by the COP1/SPA complex, but light exposure leads to the inactivation of COP1 and the stabilization of HY5. The accumulation of HY5 protein is essential for inhibiting hypocotyl elongation and promoting cotyledon expansion and chloroplast development.

42. (A) Both A and R are true and R is the correct explanation of A.
Under continuous light, the COP1 protein is actively excluded from the nucleus and moves into the cytoplasm. This translocation is a key regulatory mechanism because it physically separates COP1 from its nuclear targets, such as the transcription factor HY5. Consequently, HY5 is stabilized and can activate the genes necessary for photomorphogenesis, while the degradation machinery remains sequestered in the cytoplasm.

43. (A) Pfr binds to SPA, disrupting the COP1-SPA interaction.
In the light, the active Pfr form of phytochrome enters the nucleus and directly interacts with the SPA proteins. This binding causes the dissociation of the COP1-SPA complex, which is the functional E3 ubiquitin ligase required for the degradation of photomorphogenic promoters like HY5. By disrupting this complex, light effectively halts the degradation of these transcription factors, allowing light-induced development to occur.

44. (C) It mediated by PhyA and is not far-red reversible.
The Very Low Fluence Response is triggered by extremely small amounts of light and is primarily mediated by phytochrome A. Unlike the Low Fluence Response, VLFR is not photoreversible by far-red light. This is because even the small amount of red light present in a far-red pulse is sufficient to maintain enough Pfr to saturate the highly sensitive VLFR signaling pathway.

45. (D) Pfr form of PhyA is targeted for ubiquitin degradation.
To prevent the excessive accumulation of active phytochrome A in light, the Pfr form of PhyA is specifically targeted for rapid degradation by the 26S proteasome. This light-induced instability is a hallmark of Type I phytochromes and serves as a feedback mechanism to attenuate the signal. This degradation ensures that PhyA-mediated responses are precisely controlled as the seedling transitions to sunlight.

46. (A) III → I → II → IV
The temporal sequence of phytochrome signaling begins with the absorption of 660 nm red light by the Pr form. This energy triggers the cis-to-trans isomerization of the phytochromobilin chromophore, leading to the formation of the Pfr state. Subsequently, the Pfr form translocates into the nucleus, where it physically interacts with Phytochrome Interacting Factors to modulate gene expression and initiate light responses.

NODIA

off-target DNA
(D) Binding to the PAM and translating the altered protein

2018

226. Match the specific CRISPR-based application in List I with its corresponding modified Cas protein variant in List II.
List I: (CRISPR-based Application)
P. Transcriptional Activation (CRISPRa)
Q. Base Editing
R. RNA targeting and degradation
S. Precise gene replacement via HDR
List II: (Modified Cas Protein Variant)
1. Wild-type Cas9 with donor template
2. dCas9 fused to a potent activation domain (e.g., VP64)
3. Cas13 enzyme
4. Cas9 nickase (nCas9) fused to a deaminase
(A) P-2, Q-4, R-3, S-1
(B) P-4, Q-2, R-1, S-3
(C) P-2, Q-1, R-4, S-3
(D) P-1, Q-4, R-3, S-2

2022

227. Transgene-free delivery of the CRISPR/Cas9 machinery into plant cells can be effectively achieved by transfecting protoplasts directly with:
(A) Pre-assembled Ribonucleoprotein (RNP) complexes
(B) Complete Agrobacterium binary vectors
(C) Highly concentrated phytohormones
(D) Empty T-DNA borders

2005

228. The delivery of CRISPR/Cas9 as an RNP complex, rather than as plasmid DNA, significantly reduces the probability of:
(A) Spontaneous cell division
(B) Protoplast survival rates
(C) sgRNA target pairing
(D) Rapid degradation-linked off-target effects

2011

229. A significant obstacle to the widespread commercial application of CRISPR/Cas9 in editing elite agricultural crops is:
(A) The universal inability of monocots to repair DNA damage
(B) Difficulty in whole plant regeneration post-delivery
(C) The complete lethality of the Cas9 protein to all chloroplasts
(D) The absolute inability to edit any coding sequences

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230. A meticulously designed CRISPR/Cas9 experiment successfully knocks out the promoter of a major ripening gene in tomato. The resulting anticipated phenotype is directly due to:
(A) Massive overexpression of the targeted ripening gene
(B) Immediate cell death of the fruit tissue
(C) Prevention of gene transcriptional initiation
(D) The rapid generation of entirely seedless fruits

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undifferentiated state and initiate a complete new developmental program.

57. (B) Responsiveness to specific developmental signals
In plant development, competency refers to the physiological state in which a cell is capable of responding to specific external or internal signals, such as hormones. A competent cell is not yet committed to a particular fate but has the potential to enter a new developmental pathway when triggered. Gaining competency is often a necessary prerequisite for subsequent differentiation or organogenesis.

58. (B) Can form multiple tissue types but not an entire fertile organism.
Pluripotency refers to the ability of a cell to differentiate into several different types of tissues or organs within the plant body. However, unlike totipotent cells, pluripotent cells lack the capacity to regenerate a complete, independent, and fertile individual plant. This concept represents a middle ground in cellular plasticity, where the developmental potential is broad but not absolute.

59. (A) Dedifferentiation
Dedifferentiation is the process by which a specialized, mature plant cell, such as a mesophyll cell, reverts to a more primitive, undifferentiated state. During this transition, the cell regains the ability to divide and typically forms an unorganized mass of tissue known as a callus. This molecular reprogramming is a fundamental requirement for initiating regeneration and transformation in plant tissue culture.

60. (C) Locked in and irreversibly committed to a specific lineage.
Determinism describes a developmental state where a cell has become irreversibly committed to a specific fate or lineage. Once a cell is determined, its future development is fixed, and it will continue along that specific pathway even if moved to a different environment. This stage follows competency and represents the final commitment before the cell undergoes the structural changes of differentiation.

61. (D) Gottlieb Haberlandt
Gottlieb Haberlandt is widely recognized as the father of plant tissue culture for his pioneering work in 1902. He was the first to theoretically propose the concept of totipotency, suggesting that every individual plant cell possesses the potential to grow into a complete plant. Although his early experiments were not successful in achieving regeneration, his ideas laid the foundation for modern biotechnology.

62. (C) I and III
Cellular regeneration requires dedifferentiation, which involves extensive molecular reprogramming and the reentry of quiescent cells into the active cell cycle. For a cell to adopt a new developmental path, it must first acquire competence, which is the ability to respond to specific inductive signals. Only after achieving competence can the cell become determined and eventually differentiate into a specific organ.

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63. (B) Altered DNA methylation and histone acetylation
The acquisition of totipotency requires a massive overhaul of the cell's gene expression profile, which is achieved through epigenetic reprogramming. This involves significant changes in DNA methylation patterns and histone modifications, such as acetylation. These molecular alterations open up tightly packed chromatin, allowing the activation of genes that were previously silenced in the differentiated state, thus restoring the cell's developmental plasticity.

64. (D) Undifferentiated plasticity
A cell that has undergone dedifferentiation but has not yet been committed to a specific organ or tissue type exists in a state of undifferentiated plasticity. In this condition, the cell is highly flexible and can be directed toward various developmental outcomes depending on the hormonal signals it receives. This stage is typical of callus cells during the early phases of tissue culture.

65. (A) Ammonium and nitrate salts
Murashige and Skoog medium is characterized by its exceptionally high concentrations of nitrogen provided in the form of both ammonium and nitrate salts. This high nitrogen content supports rapid cell division and vigorous growth in a wide range of plant species. The specific balance between these two nitrogen sources is critical for maintaining the pH stability of the medium during culture.

104. (A) Induce chromosome doubling via spindle inhibition
Colchicine is a chemical agent that binds to tubulin and prevents the formation of the spindle apparatus during mitosis. When applied to haploid plants or tissues, it blocks sister chromatid separation but allows DNA replication to continue. This results in the doubling of the chromosome number, converting a haploid cell into a fertile, homozygous diploid cell, which is essential for stabilizing new varieties.

105. (B) Endosperm failure and embryo abortion
In wide crosses between distantly related species, fertilization may occur, but the resulting embryo often aborts due to endosperm failure or genomic incompatibility. Embryo rescue involves excising the immature embryo from the seed and culturing it on a nutrient-rich medium. This technique provides the necessary support for the embryo to survive and develop into a viable plant, bypassing natural post-zygotic barriers.

106. (B) Cellulases and pectinases
Protoplasts are plant cells that have had their cell walls completely removed. This is achieved by treating tissues with a mixture of cellulases, which break down cellulose microfibrils, and pectinases, which degrade the middle lamella. Removing the wall allows for direct manipulation of the cell membrane, facilitating processes such as DNA uptake, organelle transfer, and the creation of somatic hybrids through fusion.

107. (A) Polyethylene glycol (PEG)
Polyethylene glycol is the most widely used chemical agent for inducing the fusion of isolated plant protoplasts. It works by altering the surface charge of the membranes and bringing the protoplasts into close contact, which facilitates the merging of their lipid bilayers. PEG-mediated fusion is a versatile technique that can be applied to diverse species to create somatic hybrids and cybrids.

108. (C) Fused nuclear and cytoplasmic genomes
A symmetric somatic hybrid is created by the complete fusion of two parent protoplasts, resulting in a single cell that contains the nuclear genomes and the cytoplasmic organelles from both parents. This process allows for the combination of genetic traits from species that cannot be crossed sexually. These hybrids are valuable for studying gene interactions and for introducing wild-type traits into crops.

109. (D) Single-parent nucleus with donor-derived cytoplasm
Cytoplasmic hybrids, or cybrids, are unique plants that possess the nucleus of one parent combined with the cytoplasm, including chloroplasts and mitochondria, of another parent. They are often produced by fusing a normal protoplast with one whose nucleus has been inactivated. Cybrids are particularly useful for transferring traits encoded by the organellar genomes, such as cytoplasmic male sterility or herbicide resistance, between species.

110. (C) Hairy root cultures
Agrobacterium rhizogenes is a soil-borne bacterium that naturally infects plants and induces the formation of hairy roots at the site of infection. This is caused by the transfer of Ri-plasmid T-DNA into the plant genome. In biotechnology, these hairy roots are exploited as stable, fast-growing cultures for the continuous production of valuable secondary metabolites under sterile, controlled laboratory conditions.

111. (B) Fast growth in hormone-free media
Hairy root cultures are characterized by their rapid growth rate and genetic stability on media that do not require exogenous auxins or cytokinins. This hormone-independent growth is a direct result of the expression of genes transferred from the Agrobacterium rhizogenes Ri-plasmid. These features make hairy roots highly efficient systems for the large-scale industrial production of bioactive plant secondary metabolites.

112. (A) I and II
Bioreactors are essential for the large-scale cultivation of plant cells, offering precise control over environmental parameters like pH and oxygen levels. However, plant cells are particularly sensitive to shear stress caused by the mechanical impellers in standard stirred-tank reactors. This sensitivity often necessitates the use of specialized designs, such as air-lift bioreactors, which provide gentle mixing using air bubbles.

113. (A) Cell suspension cultures of Lithospermum
Shikonin is a valuable naphthoquinone pigment with significant medicinal and industrial applications. It was the first plant secondary

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76. (A) Explant → Callus → Proembryogenic masses → Globular embryo → Torpedo embryo
Indirect somatic embryogenesis begins with the induction of callus from an explant, followed by the formation of proembryogenic masses. These masses then differentiate into globular embryos, which represent the first recognizable stage of embryogeny. The embryos further develop through the heart and torpedo stages, eventually reaching maturity and becoming capable of regenerating into a complete plant with both shoot and root.

77. (D) 2,4-Dichlorophenoxyacetic acid (2,4-D)
The synthetic auxin 2,4-D is the most frequently used growth regulator for inducing somatic embryogenesis in a vast array of plant species. It is exceptionally potent in triggering the dedifferentiation of explants and the formation of proembryogenic masses. Once these masses are established, the 2,4-D is typically removed to allow the embryos to mature and proceed through subsequent developmental stages.

78. (C) Auxin
While high levels of auxin are necessary to initiate somatic embryogenesis and form proembryogenic masses, the continued presence of auxin can inhibit the subsequent maturation of the embryos. Therefore, standard protocols involve transferring the induced tissues to a medium with significantly reduced or zero auxin. This change allows the globular embryos to progress into the heart, torpedo, and cotyledonary stages.

79. (B) The unipolar development of shoots or roots with vascular connections to the maternal callus.
Organogenesis is characterized by the unipolar development of either a shoot or a root from the tissue culture. These newly formed organs maintain a direct vascular connection with the underlying callus or explant. In contrast, somatic embryos are bipolar structures with both a shoot and root pole and do not share a vascular connection with the tissue from which they originated.

80. (D) Direct organogenesis
Direct organogenesis is a process where shoots or roots are formed directly from the surface of an explant without an intervening callus phase. This method is often preferred for clonal propagation because it significantly reduces the risk of somaclonal variation, which is more common in callus-derived plants. It utilizes the regenerative capacity of pre-existing meristematic cells or the induction of adventitious buds.

81. (A) Zeatin
Zeatin is a naturally occurring cytokinin originally discovered in maize kernels and is highly effective at inducing shoot multiplication in vitro. It promotes the activation of axillary buds and the formation of adventitious shoots. Although synthetic cytokinins like BAP are more commonly used due to their lower cost, zeatin remains a valuable tool for regenerating sensitive or recalcitrant plant species.

82. (C) I and III
Thidiazuron is a synthetic compound that can mimic both cytokinin and auxin activities, making it a powerful inducer of regeneration. In somatic embryogenesis, abscisic acid is often applied during the later stages to promote embryo maturation and prevent precocious germination. In contrast, gibberellic acid is typically used to stimulate shoot elongation rather than inhibiting it, aiding in the development of regenerated plantlets.

83. (A) Reduced middle lamella adhesion
The friability of a callus refers to its tendency to easily break apart into individual cells or small clusters. This property is primarily caused by reduced adhesion between cells, which results from the breakdown or weak synthesis of the middle lamella. Friable calli are ideal for initiating cell suspension cultures because they disperse easily when placed in a liquid medium with agitation.

84. (D) Stationary phase
In batch cell suspension cultures, the production of secondary metabolites typically reaches its peak during the stationary phase. At this stage, primary growth has slowed down or ceased due to nutrient depletion, and the cells shift their metabolic focus toward the synthesis of specialized compounds. Harvesting during this phase maximizes the yield of desired bioactive products for industrial or pharmaceutical applications.

85. (B) Balancing auxin and cytokinin
The differentiation of isolated mesophyll cells into tracheary elements is a classic model for studying plant cell specialization. This process is

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located outside the T-DNA on the plasmid, ensuring only the bacteria can use them. The vir region is never integrated into the plant genome during the transfer.

123. (A) Agrobacterium-exclusive carbon and nitrogen sources
Opines are unique chemical compounds synthesized by plant cells after they have been transformed by Agrobacterium T-DNA. These molecules serve as specialized sources of carbon, nitrogen, and energy that only the infecting Agrobacterium can metabolize. By forcing the plant to produce opines, the bacteria create a unique ecological niche that supports their growth and survival at the expense of the host.

124. (C) Processing and transferring the T-DNA
The virulence region of the Ti plasmid contains several operons that encode the proteins necessary for the recognition, processing, and transfer of the T-DNA. These proteins detect plant wound signals, create a single-stranded copy of the T-DNA, and build a secretion system to deliver it into the plant cell. The vir genes themselves are not transferred to the host plant genome.

125. (D) Initiation at the right border sequence
The transfer of T-DNA into the plant cell is a directional process that is initiated at the right border sequence. The VirD2 protein nicks the DNA at this specific site and remains covalently attached to the 5' end of the single-stranded T-DNA, guiding it through the transfer machinery. This polar mechanism ensures that the T-DNA is delivered into the host cell accurately.

126. (A) Acetosyringone perception → VirA/VirG activation → VirD1/D2 nicking → T-strand formation
The infection process begins when Agrobacterium senses phenolic compounds like acetosyringone released from wounded plant cells. This signal activates the VirA/VirG two-component system, which then induces the expression of other vir genes. The VirD1 and VirD2 proteins subsequently nick the Ti plasmid at the T-DNA borders to generate the single-stranded T-strand, which is then prepared for export.

127. (B) VirD2
VirD2 is a multifunctional protein that plays a central role in T-DNA transfer. After nicking the Ti plasmid, it covalently attaches to the 5' end of the resulting single-stranded T-DNA. In this position, VirD2 protects the T-strand from degradation and contains nuclear localization signals that guide the DNA complex through the plant cytoplasm and into the host cell nucleus.

128. (D) Phenolics (e.g., acetosyringone)
Agrobacterium specifically targets wounded plant cells by recognizing chemical signals in their exudates, particularly phenolic compounds like acetosyringone. These molecules are produced as part of the plant's defense response but are exploited by the bacteria to initiate the infection process. The detection of these phenolics triggers the activation of the virulence genes required for the transfer of the T-DNA.

129. (A) VirA
VirA is a transmembrane sensory kinase located in the Agrobacterium inner membrane that acts as the primary detector for plant-derived phenolic signals. Upon binding a phenolic molecule, VirA undergoes autophosphorylation. This event initiates the signaling cascade within the bacterium, leading to the activation of the entire virulence machinery necessary for successful T-DNA transfer into the host plant cell.

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130. (C) VirG
Following its activation by plant phenolics, the VirA sensory kinase transfers its phosphate group to the VirG response regulator. Once phosphorylated, VirG acts as a transcription factor that binds to the promoters of all other vir operons on the Ti plasmid. This activation is the critical step that ensures the high-level expression of the proteins needed for T-DNA processing.

131. (A) virB operon
The export of the T-DNA complex from Agrobacterium into the plant cell is mediated by a Type IV secretion system. This complex structural channel is composed of eleven proteins encoded by the virB operon. The VirB proteins span both bacterial membranes and the cell wall, forming a functional pilus and pore that allow the T-strand to pass directly into the host.

abnormalities like hyperhydricity or excessive callus formation during the multiplication process.

95. (B) In vitro rooting and preparation for soil transfer
The primary goal of Stage III in micropropagation is to induce root formation on the individual shoots produced during the multiplication phase. This is typically achieved by transferring the shoots to a medium with a high auxin concentration or by reducing the mineral content. Developing a functional root system is essential for the eventual survival and establishment of the plantlets in soil.

96. (B) Establishment → Multiplication → Rooting → Acclimatization
A complete micropropagation protocol follows a logical sequence of stages. First, the explant is established and sterilized in vitro. Second, the shoots are rapidly multiplied on a specific medium. Third, these shoots are induced to form roots. Finally, the resulting plantlets are acclimatized to external environmental conditions, moving from the protected lab environment to the greenhouse or field.

97. (A) High humidity and high cytokinin levels
Hyperhydricity is a physiological disorder characterized by shoots that appear water-soaked, translucent, and brittle. It is primarily caused by the combination of high humidity within the culture vessel and high levels of cytokinins in the medium. This condition leads to abnormal cell wall development and impaired stomatal function, which significantly reduces the survival rate of plantlets during the acclimatization phase.

98. (C) Pre-existing axillary meristems
Nodal segment culture is a preferred method for clonal propagation because it relies on the activation of pre-existing axillary meristems. Since these meristems are already organized structures, the resulting shoots are genetically identical to the parent plant. This approach avoids the callus phase, thereby maintaining high genetic stability and ensuring that the clonal characteristics of elite genotypes are preserved.

99. (A) Poor cuticles and sluggish stomatal control
Plantlets grown in vitro develop in a high-humidity environment, which leads to the formation of very thin cuticular waxes and non-functional stomata. When moved to the lower humidity of the greenhouse, these plantlets can rapidly lose water and wilt. Acclimatization involves gradually reducing the humidity to allow the plants to develop protective cuticles and regain control over their stomatal movements.

100. (D) Virus elimination
Thermotherapy involves exposing plant tissues to elevated temperatures for a specific period to inhibit viral replication and movement. When combined with meristem culture, it significantly increases the efficiency of virus elimination. The heat treatment reduces the viral load in the plant, making it easier to isolate a virus-free meristem tip, which can then be regenerated into a healthy, pathogen-free plant.

101. (B) Doubled haploid homozygous lines
Anther culture is a powerful tool in plant breeding because it allows for the rapid production of haploid plants from microspores. When these haploids undergo chromosome doubling, they become completely homozygous doubled haploids. This technique bypasses multiple generations of self-pollination, significantly shortening the time required to develop stable, pure-breeding lines for use in F1 hybrid production and genetic research.

102. (A) P-1, Q-3, R-2, S-4
Embryo rescue is used to overcome post-zygotic barriers in wide crosses, while anther culture produces homozygous doubled haploids. Protoplast fusion is the primary method for creating cybrids and somatic hybrids, bypassing sexual incompatibility. Meristem culture is universally recognized for producing virus-free plants. These techniques are essential components of modern plant biotechnology, each serving a distinct and critical role in crop improvement.

103. (D) Sporophytic development
In androgenesis, microspores are induced to switch from their normal gametophytic pathway, which leads to pollen formation, to a sporophytic pathway. Instead of undergoing meiotic reduction, the microspores divide mitotically to form embryos or callus. This allows for the regeneration of haploid plants, which can then be used to create homozygous lines through chromosome doubling, facilitating faster breeding and genetic analysis.

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most effectively induced by providing a specific balance of auxin and cytokinin in the culture medium. These hormones trigger the complex transcriptional and metabolic changes necessary for the cell to develop thick secondary walls and undergo programmed cell death.

86. (C) Patterned secondary wall thickenings
Tracheary element differentiation is visually characterized by the development of intricate, patterned secondary cell wall thickenings, which can be annular, spiral, or reticulate. These lignified structures provide the mechanical strength needed for water transport and are the definitive marker of a functional xylem cell. The formation of these patterns is guided by the precise organization of cortical microtubules within the cell.

87. (D) Bioactive secondary metabolites
Elicitation is a technique used in plant biotechnology to stimulate the production of secondary metabolites in cell cultures. Elicitors can be biotic, such as fungal cell wall fragments, or abiotic, such as heavy metals or UV light. These signals mimic pathogen attacks or environmental stress, triggering the plant's natural defense pathways and leading to the rapid accumulation of valuable bioactive compounds.

88. (A) Lose requirement for exogenous growth regulators
Habituation is a phenomenon where plant cells in long-term culture spontaneously regain the ability to synthesize their own growth regulators, such as auxins or cytokinins. As a result, these cells no longer require an exogenous supply of these hormones in the culture medium. This change is often stable and can interfere with experiments requiring precise control over hormone levels.

89. (B) Somaclonal variation (aneuploidy/ polyploidy)
Somaclonal variation refers to the genetic and epigenetic changes that occur in plants regenerated from tissue culture, particularly from unorganized callus. These aberrations include changes in chromosome number, such as aneuploidy and polyploidy, as well as point mutations and DNA rearrangements. While often undesirable for clonal propagation, somaclonal variation can be a source of novel traits for plant breeding.

90. (B) Agitation/aeration rate
In liquid cell suspension cultures, the availability of dissolved oxygen is a major limiting factor for cell growth. To prevent oxygen starvation, the culture must be continuously agitated, usually by shaking or using a bioreactor system. Agitation also helps to break up cell clumps and ensures that nutrients are uniformly distributed throughout the medium, supporting rapid and healthy cell division.

91. (A) Histodifferentiation
Histodifferentiation is the process by which unorganized cells within a callus begin to organize into specialized tissues and structures, such as a meristematic dome. This transition marks the end of the unorganized growth phase and the beginning of organized organ formation. It involves precise spatial control of gene expression and the establishment of cellular communication networks that guide the development of the plant.

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92. (A) Both A and R are true and R is the correct explanation of A.
Meristem tip culture is the most effective method for producing virus-free plants. This is because the apical meristem often lacks a functional vascular system, which prevents the systemic movement of viruses into the growing tip. Additionally, the extremely high rate of cell division in the meristem typically exceeds the rate of viral replication, leaving the very tip of the shoot pathogen-free.

93. (B) Stage II
Stage II of micropropagation is focused on the rapid multiplication of shoots. During this phase, the established explants are transferred to media containing higher levels of cytokinins to promote the outgrowth of axillary buds or the formation of adventitious shoots. The goal is to achieve an exponential increase in the number of potential plantlets through multiple subculturing cycles.

94. (C) Cytokinins
Cytokinins are the dominant hormones used during the multiplication stage of micropropagation. They work by overcoming apical dominance and stimulating the proliferation of axillary and adventitious shoots. Commonly used cytokinins include benzyladenine and kinetin. The concentration is carefully optimized to maximize shoot production while minimizing the risk of

metabolite to be commercially produced using large-scale cell suspension cultures of Lithospermum erythrorhizon. This achievement demonstrated the feasibility of using plant cell technology as a reliable alternative to traditional field cultivation for the production of high-value natural products for the global market.

114. (C) Product synthesis and accumulation
Two-stage bioreactor systems are designed to maximize the production of secondary metabolites. In the first stage, the medium and environment are optimized for rapid cell proliferation and biomass accumulation. In the second stage, the conditions are shifted to trigger the biosynthesis and accumulation of the desired product. This separation of growth and production phases allows for significantly higher overall yields and efficiency.

115. (A) Facilitate the release of intracellular metabolites
Many valuable plant secondary metabolites are stored within the cell's vacuoles, making their recovery difficult and often requiring the destruction of the biomass. Permeabilization is a technique used to temporarily increase the permeability of the cell membranes, allowing the products to be released into the surrounding medium. This allows for continuous harvesting and reuse of the cultured plant cells.

116. (D) Elicitation
Elicitation is a strategic approach in plant cell culture where cells are exposed to specific chemical or physical stimuli to induce the production of secondary metabolites. These elicitors mimic the signals of pathogen attack or environmental stress, activating the plant's defense-related metabolic pathways. This technique is widely used to significantly increase the concentration of bioactive compounds in industrial-scale bioreactors.

117. (B) Clonal propagation of elite timber genotypes
Forestry programs utilize somatic embryogenesis for the mass clonal propagation of elite timber trees with superior growth and wood quality traits. This method allows for the production of thousands of identical embryos from a single high-value genotype. These embryos can be encapsulated into synthetic seeds, facilitating efficient handling, storage, and planting, which is essential for large-scale reforestation and sustainable timber production.

118. (C) Protection from shear stress during extraction
Immobilizing plant cells in a matrix, such as calcium alginate, provides a stable environment that protects them from the mechanical shear stress encountered in bioreactors. This technique also facilitates the separation of the biomass from the culture medium, simplifying the extraction of secreted metabolites. Immobilized cells often exhibit enhanced longevity and metabolic stability, making them suitable for long-term continuous production processes.

119. (D) The T-DNA region of the Ti plasmid
The ability of Agrobacterium tumefaciens to cause crown gall disease is due to the transfer of a specific segment of DNA, known as the T-DNA, into the host plant's genome. This T-DNA is part of the larger Tumor-inducing plasmid. Once integrated, the T-DNA genes are expressed in the plant cell, leading to abnormal growth and the production of specialized nutrients.

120. (A) 25-base pair direct repeat border sequences
The T-DNA region is physically defined by two conserved 25-base pair sequences located at its ends, known as the left and right borders. These direct repeats are the only essential cis-elements required for the recognition and excision of the T-DNA by the bacterial virulence machinery. Any DNA sequence placed between these borders will be successfully transferred from the Agrobacterium into the host.

121. (B) Auxins and cytokinins
The oncogenes located within the T-DNA of wild-type Agrobacterium encode enzymes that catalyze the synthesis of auxins and cytokinins. Once integrated into the plant genome, these genes are expressed under the control of eukaryotic-like promoters. The resulting overproduction of these hormones triggers uncontrolled cell division at the site of infection, leading to the formation of the characteristic crown gall tumor.

122. (A) I, II and III
Agrobacterium rhizogenes induces hairy roots, while Ti plasmids induce crown galls. Both transfer T-DNA containing opine synthesis genes into the plant genome. However, the genes required for the catabolism of these opines are

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vector and facilitate its delivery into the plant cell. This cooperative action is the foundation of the binary system.

142. (A) Both A and R are true and R is the correct explanation of A.
Co-integrate vectors are assembled through a single crossover event between an intermediate vector and a disarmed Ti plasmid within the Agrobacterium cell. This process requires a shared region of DNA homology to facilitate recombination. Because the intermediate vector lacks a functional origin of replication for Agrobacterium, it can only be maintained if it physically integrates into the larger resident Ti plasmid.

143. (B) Cauliflower Mosaic Virus (CaMV) 35S promoter
The CaMV 35S promoter is a powerful and widely used constitutive promoter in plant biotechnology. It drives high-level gene expression in nearly all tissues and stages of development, particularly in dicotyledonous plants. Because of its strength and reliability, it is the standard choice for expressing selectable markers and genes of interest where uniform, high-level protein production is desired throughout the plant.

144. (D) Polyadenylation (poly-A) signal
To ensure that a transgene is correctly processed and expressed in a eukaryotic plant cell, it must include a proper polyadenylation signal. This sequence, typically derived from genes like the nopaline synthase (nos) gene, signals the end of transcription and directs the addition of a poly-A tail to the mRNA. This tail is essential for mRNA stability, nuclear export, and efficient translation.

145. (A) Between the Right and Left Borders
For multiple genes, such as a selectable marker and multiple genes of interest, to be successfully transferred into the plant genome, they must all be located within the boundaries defined by the T-DNA borders. The Agrobacterium machinery transfers the entire DNA segment from the right border to the left border as a single unit. This ensures the co-inheritance of all the engineered traits.

146. (A) I → II → III → IV
The plant transformation workflow begins with cloning the target gene into a binary vector in E. coli. Next, the vector is transferred into Agrobacterium. The bacteria are then co-cultivated with plant explants to allow T-DNA transfer. Finally, the transformed cells are selected on a medium containing antibiotics or herbicides, which allows only the cells that integrated the T-DNA to survive and regenerate.

147. (A) Confer a survival advantage to transformed cells
Selectable marker genes are critical in plant transformation because only a very small percentage of cells successfully integrate the foreign DNA. By including a gene that provides resistance to a lethal agent, such as an antibiotic or herbicide, researchers can selectively grow only the transformed cells. This survival advantage allows for the efficient identification and regeneration of transgenic plants from a large population.

148. (D) Kanamycin
The nptII gene, which encodes neomycin phosphotransferase II, is one of the most common selectable markers used in plant transformation. It provides resistance to several aminoglycoside antibiotics, most notably kanamycin. By expressing this gene, transformed plant cells can survive on media that would otherwise be lethal, allowing for the successful selection and regeneration of transgenic shoots in many dicot species.

149. (B) Phosphorylating the antibiotic molecule
The nptII enzyme provides resistance to kanamycin by catalyzing the phosphorylation of the antibiotic molecule. This chemical modification prevents the kanamycin from binding to its target site on the plant cell's ribosomes, thereby neutralizing its toxic effect on protein synthesis. This mechanism allows the transformed cells to grow and divide normally in the presence of the selective agent during tissue culture.

150. (C) Hygromycin B
The hpt gene, also known as hph, encodes the enzyme hygromycin phosphotransferase, which detoxifies the antibiotic hygromycin B. Like kanamycin, hygromycin B inhibits protein synthesis, but it is often more effective at killing

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132. (A) I and II
Once inside the plant cell, the single-stranded T-DNA is protected from degradation by two Agrobacterium-derived proteins. VirD2 remains attached to the 5' end, while multiple copies of VirE2 coat the entire length of the T-strand. Together, these proteins form a stable ribonucleoprotein complex that traverses the host cytoplasm and ensures the T-DNA reaches the nucleus intact.

133. (B) VirD2 and VirE2
To enter the plant nucleus, the T-DNA complex must utilize the host's active transport machinery. Both VirD2 and VirE2 proteins contain specific nuclear localization signals that are recognized by plant importin proteins. These signals are essential for the targeted movement of the large T-DNA complex through the nuclear pores, ensuring the foreign DNA reaches its final destination for integration.

134. (C) Non-Homologous End Joining (NHEJ)
The integration of the T-DNA into the plant genome is primarily mediated by the host cell's own DNA repair mechanisms, specifically the Non-Homologous End Joining pathway. This process involves the joining of the T-DNA ends to double-strand breaks that occur naturally in the plant's chromosomal DNA. Because NHEJ does not require sequence homology, T-DNA integration is often random and unpredictable.

135. (D) Engineer delivering a functional DNA cassette
Agrobacterium is often referred to as a natural genetic engineer because of its unique ability to perform trans-kingdom gene transfer. It possesses a specialized machinery designed to deliver a specific DNA cassette into a host organism's genome. In biotechnology, this system is modified to transfer genes of interest, making it the most widely used tool for creating genetically modified plants.

136. (A) Insufficient phenolic inducer production
The natural resistance of many monocots to Agrobacterium-mediated transformation is largely due to their failure to produce sufficient amounts of phenolic signaling molecules, such as acetosyringone, upon wounding. Without these signals, the bacterial vir genes are not activated, and T-DNA transfer cannot occur. Modern transformation protocols often overcome this by adding synthetic acetosyringone to the co-cultivation medium.

137. (B) The T-DNA oncogene sequences
A "disarmed" Ti plasmid is created by deleting the natural oncogenes from the T-DNA region while keeping the 25-bp border sequences intact. This modification prevents the formation of crown gall tumors in the host plant. By replacing these oncogenes with desirable genes and selectable markers, researchers can use Agrobacterium to create transgenic plants that grow and develop normally.

138. (A) Between the left and right T-DNA borders
In engineered plant transformation vectors, the multiple cloning site must be located within the T-DNA region, specifically between the left and right border sequences. This ensures that any gene inserted into the MCS will be recognized by the bacterial transfer machinery and successfully delivered into the plant genome. The borders define the physical limits of the DNA segment to be transferred.

139. (A) On two separate plasmids in Agrobacterium
The binary vector system uses two separate plasmids within the same Agrobacterium cell. One plasmid, the binary vector, contains the engineered T-DNA with the genes of interest. The other plasmid, known as the helper plasmid, provides the vir genes in trans. This system is more efficient and easier to manipulate than older methods, making it the standard for plant transformation.

140. (C) Easier pre-manipulation in E. coli
One of the primary advantages of the binary vector system is the small size of the binary vector plasmid, which allows it to be easily manipulated and cloned in E. coli. Once the desired construct is verified, it can be transferred into Agrobacterium for plant transformation. This separation of tasks simplifies the molecular biology workflow compared to the larger and more complex co-integrate vectors.

141. (D) Functional vir gene products
In the binary vector system, the helper plasmid provides all the necessary vir gene products required for T-DNA processing and transfer. Although the vir genes are on a separate plasmid from the T-DNA, they function in trans to recognize the T-DNA borders on the binary

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66. (C) Sucrose
Sucrose is the most commonly used carbon and energy source in plant tissue culture media. It is easily transported across cell membranes and efficiently metabolized by plant tissues into glucose and fructose. In addition to providing energy for growth and division, sucrose also acts as an osmoticum, helping to maintain the proper osmotic potential of the culture environment.

67. (A) Phospholipid biosynthesis and cell wall formation
Myo-inositol is an essential organic supplement in many tissue culture media because it serves as a precursor for various metabolic pathways. It is particularly important for the biosynthesis of phospholipids, which are structural components of cell membranes, and for the production of cell wall polysaccharides. Its presence enhances cell growth and division, contributing to the overall health of the cultured tissues.

68. (D) Iron
Iron is a vital micronutrient in tissue culture media, but it can easily precipitate and become unavailable to plants at standard pH levels. To prevent this, iron is provided as a chelate, most commonly with Ethylenediaminetetraacetic acid. This complex keeps the iron soluble and accessible to the plant cells over a wide range of pH conditions, ensuring consistent metabolic activity.

69. (B) 5.6 - 5.8
The pH of plant tissue culture media is typically adjusted to between 5.6 and 5.8 before autoclaving. This slightly acidic range is optimal for the solubility of nutrients and the activity of growth regulators. Maintaining this pH is also important for the proper solidification of agar; if the medium is too acidic, the agar may fail to gel correctly.

70. (C) Adsorbing inhibitory phenolic compounds
Activated charcoal is often included in tissue culture media to improve the growth environment by adsorbing toxic metabolites and inhibitory phenolic compounds. These substances are frequently released by explants during the early stages of culture and can cause tissue browning and death. By sequestering these inhibitors, activated charcoal promotes better establishment and regeneration of sensitive plant species and tissues.

71. (D) Coenzymes for critical metabolic pathways
Vitamins such as thiamine are added to culture media because they function as essential coenzymes in various primary metabolic pathways. For example, thiamine is a critical cofactor in carbohydrate metabolism and the citric acid cycle. Although plants can synthesize these vitamins in vivo, isolated tissues in culture often require an exogenous supply to maintain high rates of growth and division.

72. (B) II, III and IV
In tissue culture media, macronutrients are required in millimolar amounts, while micronutrients like copper and molybdenum are needed in much smaller quantities. Sucrose serves the dual role of a carbon source and an osmotic regulator. While agar is the primary solidifying agent, it is used because it is inert and not digested by plant cells, providing a stable support.

73. (B) Coconut milk
Coconut milk is a complex, undefined organic supplement that contains a rich mixture of amino acids, vitamins, sugars, and natural growth regulators like cytokinins. It is often added to media to promote the growth of difficult-to-culture species or to induce somatic embryogenesis. Because its exact chemical composition can vary, it is referred to as an undefined or complex additive.

74. (B) Roots
Based on the classical Skoog and Miller model, the balance of auxin and cytokinin in the medium determines the type of organogenesis. A high ratio of auxin to cytokinin promotes the formation and development of roots from the cultured tissue. This principle is widely applied in micropropagation to induce rooting in regenerated shoots before they are transferred to the soil.

NODIA

75. (A) Continuous unorganized callus growth
When the concentrations of auxin and cytokinin in the culture medium are approximately equal, the tissue typically undergoes rapid cell division without forming organized structures. This results in the proliferation of an unorganized mass of cells known as a callus. Maintaining this intermediate hormonal balance is the primary method for establishing and subculturing callus lines for research or industrial use.

non-transformed cells in species that have a high natural tolerance to other antibiotics. This makes hpt a valuable selectable marker for transforming a wide variety of plant species.

151. (D) Glufosinate
The bar gene encodes the enzyme phosphinothricin acetyltransferase, which provides resistance to the herbicide glufosinate. The enzyme detoxifies the herbicide by acetylating it, preventing it from inhibiting glutamine synthetase, a key enzyme in nitrogen metabolism. The bar gene is widely used as both a selectable marker in the laboratory and a commercial trait for herbicide tolerance in major crops like corn and soybean.

152. (A) P-3, Q-4, R-2, S-1
Plant transformation utilizes diverse selectable markers to identify transgenics. The bar gene provides resistance to glufosinate, while hpt confers tolerance to hygromycin. The nptII gene is used for kanamycin selection, and cp4-epsps is the standard marker for glyphosate resistance. These genes allow researchers to selectively recover transformed tissues by applying the corresponding selective agent to the growth medium in tissue culture.

153. (B) Enabling utilization of novel carbon sources
Unlike negative selection, which kills non-transformed cells, positive selection systems provide transformed cells with the unique ability to utilize a specific nutrient that they otherwise could not. For example, the pmi gene allows cells to use mannose as a carbon source. This approach is often considered more environmentally friendly as it avoids the use of antibiotics or herbicides during the early stages of plant regeneration.

154. (B) Eradicate contaminating Agrobacterium
After the co-cultivation period, it is essential to stop the growth of the Agrobacterium to prevent it from overgrowing and killing the plant tissues. Antibiotics like cefotaxime or timentin are added to the culture medium specifically for this purpose. These "bacteriostatic" or "bactericidal" agents target the bacteria without harming the plant cells, ensuring a clean environment for the selection and regeneration process.

155. (A) High inherent tolerance to the antibiotic
Kanamycin is often ineffective for selecting transformed cereal cells because many monocot species possess a high natural level of tolerance to the antibiotic. This inherent resistance makes it difficult to distinguish between transformed and non-transformed tissues on kanamycin-containing media. Consequently, researchers working with cereals usually prefer other markers, such as those providing resistance to hygromycin or specific herbicides like glufosinate.

NODIA

156. (C) Allow spatial localization of gene expression
Scorable markers, or reporter genes, are used to visually identify transformed cells or to study the activity of specific promoters. Unlike selectable markers, they do not provide a survival advantage. Instead, they produce a visible signal, such as a color change or fluorescence, that allows researchers to track where and when a gene is being expressed within the plant tissues and organs.

157. (D) Blue with X-Gluc substrate
The uidA gene encodes the enzyme beta-glucuronidase, which is used in the popular GUS histochemical assay. When the colorless substrate X-Gluc is added to plant tissues expressing the GUS enzyme, it is cleaved to form an insoluble blue precipitate. This allows for the precise visualization of gene expression patterns at the cellular level, making GUS a powerful tool for promoter analysis.

158. (C) It requires the destruction of the tissue being analyzed.
A major disadvantage of the standard histochemical GUS assay is that it is a destructive process. The tissue must be fixed and treated with the X-Gluc substrate, which kills the cells. Therefore, it is impossible to follow the expression of the gene over time in the same living plant sample. This limitation has led to the increased use of non-destructive markers like GFP.

159. (B) Green Fluorescent Protein (GFP)
Green Fluorescent Protein is an ideal reporter for real-time, non-destructive monitoring of gene expression in living plants. It does not require any exogenous substrates or destructive processing; the protein simply fluoresces when exposed to blue or UV light. This allows researchers to observe the dynamic movement of proteins and the spatial patterns of gene expression in the same plant throughout its development.

215. (D) Generating blunt DSBs upstream of the PAM
Once the Cas9 protein binds to its target site, it uses its RuvC and HNH catalytic domains to cut both strands of the DNA. This cleavage occurs three nucleotides upstream of the PAM sequence, resulting in a blunt-ended double-strand break. This precise cut then triggers the host cell's DNA repair machinery, which can be exploited to introduce targeted mutations or to facilitate gene insertion.

216. (A) P-3, Q-1, R-2, S-4
The CRISPR system and TALENs use different mechanisms for DNA cleavage. In CRISPR, the spacer sequence determines specificity through RNA-DNA pairing, while the PAM is a mandatory motif for Cas9 binding. The RuvC domain specifically cuts the non-target DNA strand. In TALENs, the FokI domain must undergo dimerization to become active. Understanding these individual components is essential for the successful design and application of genome editing tools.

217. (B) The sgRNA guides cleavage at unintended similar loci
Off-target effects occur when the Cas9-sgRNA complex binds to and cleaves genomic sites that are similar, but not identical, to the intended target sequence. This is a concern in complex plant genomes where many genes belong to large families with high sequence similarity. Researchers use sophisticated software and modified Cas proteins to minimize these risks and ensure the precision of the genome editing process.

218. (A) Fusing dCas9 to a cytidine deaminase (C to T)
Cytosine Base Editors are advanced tools that allow for precise single-nucleotide changes without creating a double-strand break. They consist of a catalytically inactive or "dead" Cas9 protein fused to a cytidine deaminase enzyme. When guided to a target site, the deaminase converts cytosine to uracil, which the cell's repair machinery eventually turns into thymine, enabling highly specific point mutations in the genome.

219. (A) Segregating Cas9 cassettes through sexual crossing
To produce genome-edited crops that are considered transgene-free, researchers often integrate the CRISPR machinery into the genome and then remove it through sexual crossing in subsequent generations. The edited site and the Cas9 cassette segregate independently, allowing for the selection of progeny that carry the desired mutation but have lost the foreign DNA. This approach is vital for meeting certain regulatory and consumer requirements.

220. (C) Cas12a (Cpf1)
Cas12a is an alternative CRISPR nuclease that offers several advantages over Cas9. One key difference is that Cas12a creates a 5-nucleotide staggered cut, or "sticky ends," rather than the blunt ends produced by Cas9. These staggered ends can be more useful for precise gene insertion. Additionally, Cas12a is a smaller protein and processes its own guide RNAs, making it well-suited for multiplexing and complex editing tasks.

221. (D) Recognition of specific T-rich PAM sequences
Unlike Cas9, which requires a G-rich PAM, the Cas12a nuclease recognizes T-rich PAM sequences, such as 5'-TTTV-3'. This property makes Cas12a particularly valuable for targeting AT-rich regions of the genome, such as many plant promoters and non-coding sequences. By expanding the range of available PAM sequences, Cas12a increases the number of genomic sites that can be precisely edited in diverse plant species.

222. (A) Both A and R are true and R is the correct explanation of A.
CRISPR/Cas9 is much more efficient for multiplex genome editing than ZFNs or TALENs. This is because the Cas9 protein can be guided by multiple small RNA molecules, each targeting a different gene. In contrast, ZFNs and TALENs require the engineering of a completely new, large protein for every single target site. This modularity makes CRISPR the preferred system for complex traits involving multiple genes.

223. (B) Vector backbone and Cas9 transgene sequences
When developing a commercial genome-edited crop, it is essential to ensure that the final variety does not contain any foreign DNA from

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membrane, where the electrical pulses can more easily create pores. Transforming protoplasts via electroporation is a standard technique for transient expression studies and for generating stable transgenic lines in species where protoplast regeneration is possible.

170. (B) Enables organelle-level transformation
A unique advantage of biolistics over Agrobacterium-mediated transformation is its ability to deliver DNA into organelles like chloroplasts and mitochondria. The physical force of the microprojectiles can penetrate multiple membranes, allowing for the stable integration of genes into the organellar genomes. This technique, known as biolistic chloroplast transformation, is important for high-level protein production and studying organellar gene function in plants.

171. (A) Complex and multicopy integration patterns
One of the main drawbacks of biolistics is the tendency for the transgene to integrate into the plant genome in complex, multiple-copy patterns. These multi-copy insertions often lead to genomic instability and gene silencing, where the expression of the transgene is lost over time. This contrasts with Agrobacterium-mediated transformation, which more frequently results in the integration of a single, clean copy of the T-DNA.

172. (A) I, II and IV
Direct gene transfer methods offer alternatives to Agrobacterium. PEG-mediated transformation requires the removal of the cell wall to allow DNA uptake. Electroporation uses different types of electrical pulses to create membrane pores. Microinjection involves the precise delivery of DNA into a single cell under microscopic control. Contrary to some beliefs, biolistics is a highly effective method for transforming monocots like wheat and maize.

173. (D) Verify the physical presence of the transgene
After a transformation experiment, the first step in molecular analysis is to extract genomic DNA from the regenerated plants. This DNA is used in PCR assays to confirm that the transgene has been successfully integrated into the host genome. Verifying the physical presence of the foreign DNA is essential for identifying which plants are true transgenics and which are escapes from the selection process.

174. (C) Removes plant polysaccharides and polyphenols
The CTAB method is a popular choice for plant DNA extraction because it effectively addresses the challenge of contaminating polysaccharides and polyphenolic compounds. These substances can interfere with downstream molecular techniques like PCR and restriction digestion. CTAB acts as a detergent that binds to DNA while keeping these inhibitors in solution, allowing for the isolation of high-quality genomic DNA suitable for molecular screening.

175. (B) Amplification of a fragment of expected size
In a PCR screen for transgenics, a positive result is indicated by the presence of a sharp DNA band on an agarose gel. This band must correspond to the expected size of the targeted transgene fragment. The appearance of this band confirms that the specific DNA sequence was present in the genomic extract and was successfully amplified by the primers, providing initial evidence of transformation.

176. (D) Transcription of the transgene into mRNA
While standard PCR detects the presence of the transgene in the DNA, RT-PCR is used to determine if that gene is actually being transcribed into mRNA. This involves converting the extracted RNA into cDNA and then amplifying the target sequence. Positive RT-PCR results confirm that the transgene is functional and is being expressed within the plant's cells, which is a critical step in trait development.

177. (A) Detecting persistent Agrobacterium contamination
When screening T0 plants via PCR, it is common practice to include primers for a bacterial gene like virG that is not part of the T-DNA. If a band is detected for virG, it indicates that the plant sample is contaminated with residual Agrobacterium. This control is vital because such contamination can lead to false-positive results, making it appear that the plant is transformed when it is not.

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178. (C) The nptII sequence is present in the sample.
A positive PCR result for a gene like nptII proves only that the specific DNA sequence is present in the extracted sample. It does not provide information about the number of copies integrated, the location of the integration, or whether the protein is being correctly

CHAPTER 13
Phenome Genome Relationships

2012

1. Which concept specifically refers to the complete set of phenotypes expressed by a genome throughout an organism's life?
(A) Phenome
(B) Genotype
(C) Phene
(D) Plastome

2001

2. In the context of quantitative genetics, which factor primarily distinguishes a genotype from a phenotype?
(A) The genotype fluctuates dynamically over time
(B) The phenotype refers exclusively to inherited DNA
(C) The phenotype includes environmental interactions
(D) The genotype is defined by visible physical traits

2018

3. What defines the fundamental, irreducible unit of a phenotype according to classical phenomics?
(A) A phene
(B) A complex trait
(C) A pleiotropic gene
(D) A quantitative trait locus

2011

4. Identify the INCORRECT statement regarding the distinction between genome and phenome.
(A) The genome sequence remains relatively static across the vast majority of differentiated plant tissues.
(B) The phenome is a highly dynamic entity that is fundamentally context-dependent and transient.
(C) The phenome represents the observable physical and biochemical manifestation of the specific genome.
(D) The genome predetermines the final phenome regardless of any external environmental influences.

2023

5. Which of the following is an example of a factual distinction between a genotype and a phenotype?
(A) Genotype changes with temperature, while phenotype remains constant
(B) Genotype refers to genetic makeup, while phenotype is the expressed observable trait
(C) Phenotype is inherited exactly as DNA sequences
(D) Genotype includes developmental plasticity

2015

6. Which methodology is most appropriate for capturing the complete phenome of an agricultural crop?
(A) Single-gene knockout observation
(B) Traditional destructive sampling at a single growth stage
(C) High-throughput non-destructive phenotyping across environments
(D) Visual scoring of a single morphological trait

2016

7. The central dogma of molecular biology bridges the gap between genome and phenome primarily through which sequence of biological processes?
(A) Replication and meiosis
(B) Segregation and independent assortment
(C) Mutation and genetic drift
(D) Transcription and translation

2024

8. What is the effect of post-translational modifications on the relationship between genome and phenome?
(A) They introduce complexity, causing a single gene to potentially produce multiple phenes
(B) They simplify the predictive models of phenotypes
(C) They bypass the central dogma entirely
(D) They prevent the environment from interacting with the genotype

2014

9. In understanding the pathway from genome to phenome, which process acts as the direct immediate output of transcription?
(A) Polypeptide assembly

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RNAs. These siRNAs guide the degradation of the corresponding mRNA transcripts, effectively preventing the production of the transgenic protein. This process is a major challenge in developing stable, high-expressing transgenic varieties.

188. (C) 3:1 (tolerant to susceptible)
If a transgenic plant has a single T-DNA insertion at a single locus, it will behave like a traditional Mendelian trait. Upon self-pollination, the T1 progeny will segregate in a 3:1 ratio of tolerant to susceptible individuals. This simple inheritance pattern is highly desirable in breeding programs as it simplifies the process of making the trait homozygous and stable in subsequent generations.

189. (D) Western blotting or ELISA
To verify that a transgenic plant is producing a functional protein, such as the Bt toxin, researchers use protein-based assays like Western blotting or ELISA. These techniques use specific antibodies to detect and quantify the target protein in plant extracts. Confirming protein accumulation is essential for evaluating the effectiveness of the trait and ensuring it meets the desired performance levels in the field.

190. (C) Genomic sequences adjacent to the insertion site
Flanking sequence analysis is used to identify the precise location of the transgene within the host genome. Techniques like Thermal Asymmetric Interlaced PCR allow researchers to amplify and sequence the plant DNA immediately adjacent to the T-DNA borders. This information is vital for intellectual property protection and for ensuring the transgene has not disrupted an important endogenous gene or integrated into an unstable region.

191. (B) Target insect larvae (e.g., Helicoverpa)
The effectiveness of a Bt-cotton plant is directly evaluated by exposing the tissues to the target pest, such as bollworm larvae, in a controlled bioassay. Researchers monitor the mortality and growth rates of the insects to determine if the plant is producing sufficient levels of the toxin. This phenotypic verification is the ultimate test of the transgenic plant's performance and commercial value.

192. (C) A is true but R is false.
The CP4-EPSPS gene confers herbicide tolerance because the enzyme it encodes is naturally insensitive to inhibition by glyphosate. While the plant's endogenous enzyme is blocked, the transgenic version allows the shikimate pathway to continue functioning normally. The provided reason is incorrect because the resistance is due to the enzyme's structural properties, not the active degradation or detoxification of the glyphosate molecule.

193. (A) Aromatic amino acids (e.g., Phenylalanine)
The EPSPS enzyme is a key component of the shikimate pathway, which is responsible for the synthesis of the essential aromatic amino acids phenylalanine, tyrosine, and tryptophan. Glyphosate works as a herbicide by specifically inhibiting this enzyme, leading to a depletion of these amino acids and the eventual death of the plant. This pathway is unique to plants, fungi, and some bacteria.

194. (C) A specific genomic T-DNA insertion event
In the context of GMO regulation, a "transformation event" refers to the unique instance where a specific piece of T-DNA integrated into a particular location in the host genome. Each event is unique in its integration site and copy number. Commercial transgenic varieties are developed from a single, well-characterized event that has been rigorously tested for performance, stability, and biosafety before approval.

NODIA

195. (A) Compositional equivalence to conventional crops
Substantial equivalence is a fundamental concept in the safety assessment of GM crops. It involves comparing the compositional and nutritional profile of the GMO to its non-GM counterpart. This assessment looks at macro and micronutrients, as well as naturally occurring toxins and anti-nutrients. If the GM crop is found to be substantially equivalent, it is considered as safe as the traditional version.

196. (D) Delay evolved Bt-resistance in target pests
The refuge strategy is a mandatory management practice designed to prevent target insects from developing resistance to Bt toxins. By planting a portion of the field with non-Bt crops, farmers provide a habitat for pests that remain susceptible to the toxin. These susceptible insects can then

mate with any rare resistant individuals that emerge from the Bt crop, diluting the resistance genes in the population.

197. (B) Stability in simulated gastric fluid
One of the key safety tests for transgenic proteins is the pepsin resistance assay, which measures the protein's stability in simulated gastric fluid. Most known food allergens are resistant to digestion in the stomach. Therefore, if a transgenic protein is rapidly degraded under these conditions, it is considered less likely to pose an allergenic risk to humans or animals consuming the GM crop.

198. (C) Escaping to non-GM crops or wild relatives
Gene flow is the movement of genes between different populations or species, often through pollen dispersal. In biosafety assessments, researchers study the risk of a transgene escaping from a GM crop into nearby conventional fields or wild-type relatives. This is particularly important for crops with wild relatives in the same region, as it could potentially lead to the development of herbicide-resistant weeds.

199. (D) Combining multiple transgenes in one variety
Stacking, or gene pyramiding, involves the combination of multiple transgenic traits into a single plant variety. This can be achieved through sexual crossing between two transgenic lines or by transforming a plant with multiple genes simultaneously. Stacking is widely used to provide broad-spectrum insect resistance and multiple herbicide tolerances, improving the overall performance and durability of the transgenic crop in the field.

200. (A) Primers targeting the T-DNA/genomic junction
Because every transformation event has a unique integration site, the sequences at the junction between the T-DNA and the host genome serve as a molecular signature. Regulatory laboratories use PCR primers specific to these junction sequences to definitively identify the presence of a particular GMO event in a sample. This method is highly specific and allows for the precise detection and monitoring of transgenic products.

201. (B) Non-Homologous End Joining (NHEJ)
Non-Homologous End Joining is the predominant natural pathway for repairing double-strand breaks in plant cells. This mechanism involves the direct ligation of the broken DNA ends without the need for a repair template. Because it is often imprecise, NHEJ can introduce small insertions or deletions at the break site, making it a powerful tool for generating gene knockouts during targeted genome editing.

202. (A) P-1, Q-2, R-4, S-3
Genome editing outcomes are determined by the DNA repair pathway utilized after cleavage. NHEJ typically results in unpredictable indels, while HDR uses a template for precise sequence replacement. Microhomology-Mediated End Joining often causes deletions between short repeated sequences. Base editing allows for specific single nucleotide changes without creating a double-strand break. These pathways are exploited to achieve different types of genomic modifications.

203. (A) Error-prone Non-Homologous End Joining
To create a gene knockout, researchers utilize a nuclease to cut the target DNA and then rely on the cell's natural Non-Homologous End Joining repair pathway. Because this process is inherently error-prone, it frequently results in small indels at the site of the break. If these mutations occur within a coding region, they often lead to frameshifts and premature stop codons, effectively disrupting gene function.

204. (C) HDR is active mainly in S/G2 cell cycle phases
Homology-Directed Repair is much less frequent than NHEJ in plant cells, largely because it is restricted to the S and G2 phases of the cell cycle when a sister chromatid is available as a template. This limited temporal window makes it challenging to achieve precise gene knock-ins or sequence replacements. Researchers are currently exploring various strategies to enhance HDR efficiency for more controlled genome editing.

205. (D) Frameshift leading to premature stop codons
When NHEJ repairs a double-strand break within an exon, the resulting small insertions or deletions often change the reading frame of the gene. These frameshift mutations typically lead to the appearance of a premature stop codon, resulting in a truncated and non-functional protein. This is the most common mechanism for achieving targeted gene knockouts using

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CRISPR or other engineered nuclease systems in plant biotechnology.

206. (C) TALENs
Transcription Activator-Like Effector Nucleases use modular DNA-binding domains where each module consists of 33-35 amino acids. Two specific residues, called the Repeat Variable Di-residue, determine the module's binding specificity to a single nucleotide. By stringing these modules together, researchers can design TALENs to recognize almost any specific DNA sequence with high precision, making them a versatile tool for genome editing.

207. (B) FokI
Both Zinc Finger Nucleases and TALENs utilize the non-specific cleavage domain of the FokI restriction enzyme to create double-strand breaks. This domain is fused to a customizable DNA-binding protein that directs it to the target site. Because FokI requires dimerization to be catalytically active, two nuclease units must bind to opposing strands of the DNA, enhancing the specificity of the cleavage process.

208. (D) Dimerization
The catalytic activity of the FokI cleavage domain is strictly dependent on its ability to form a dimer. In the context of ZFNs and TALENs, this means that two independent proteins must bind to the target DNA in close proximity and in the correct orientation. This requirement for dimerization serves as a critical built-in safety mechanism that significantly reduces the risk of unintended off-target cleavage.

209. (A) Opposing TALEN pairs with optimal spacing
To successfully generate a double-strand break using TALENs, a pair of proteins must be designed to bind to the sense and antisense strands of the DNA. These two binding sites must be separated by a short "spacer" region that allows the FokI domains to meet and dimerize. This dual-targeting requirement ensures that cleavage only occurs at the precise site where both TALENs bind correctly.

210. (C) Context-dependent module interaction affects binding
A significant challenge in designing Zinc Finger Nucleases is that the individual zinc finger modules often interact with their neighbors, meaning that the binding specificity of one module can be influenced by the adjacent ones. This context-dependency makes the design of highly specific ZFNs more complex and less predictable than TALENs or CRISPR, where the individual recognition elements are more independent and modular.

211. (A) Bacterial adaptive immune system against phages
The CRISPR/Cas system is a natural adaptive immune mechanism found in many bacteria and archaea. It works by capturing small pieces of DNA from invading viruses and incorporating them into the bacterial genome. These sequences are later used as guides to recognize and degrade the same virus if it attacks again. Scientists have repurposed this elegant system as a powerful tool for targeted genome editing.

212. (A) Both A and R are true and R is the correct explanation of A.
The Cas9 protein functions as a generic endonuclease that requires an external guide to locate specific DNA sequences. The single guide RNA provides this specificity through base pairing with the target genomic site. Because Cas9 lacks inherent sequence-specific binding domains of its own, the sgRNA is the sole determinant of where the double-strand break will occur within the complex plant genome.

NODIA

213. (B) 5'-NGG-3'
For the widely used SpCas9 enzyme, the target DNA sequence must be immediately adjacent to a short motif known as the Protospacer Adjacent Motif. The standard PAM for SpCas9 is 5'-NGG-3'. If this specific sequence is not present, the Cas9 protein will not bind to the site, even if the guide RNA is perfectly complementary. The PAM is a critical requirement for DNA recognition.

214. (C) crRNA and tracrRNA
In its natural bacterial form, the CRISPR system uses two separate RNA molecules: the CRISPR RNA, which contains the targeting sequence, and the trans-activating CRISPR RNA, which acts as a scaffold for Cas9. For genome editing applications, these two molecules are typically fused into a single guide RNA. This synthetic fusion simplifies the delivery of the components and improves the efficiency of the editing system.

synthesized. PCR is a highly sensitive detection tool, but further molecular analysis is required to confirm the stability and functionality of the transgene.

179. (A) 260 nm / 280 nm
The purity of isolated genomic DNA is routinely assessed using spectrophotometry by measuring the ratio of absorbance at 260 nm and 280 nm. DNA absorbs light maximally at 260 nm, while proteins absorb at 280 nm. A ratio between 1.8 and 2.0 is generally considered an indicator of high-quality DNA, relatively free of protein contamination, which is suitable for demanding molecular applications.

180. (D) Endogenous housekeeping gene (e.g., Actin)
To ensure that a negative PCR result is truly due to the absence of the transgene rather than a failure of the reaction, researchers include a positive control. This control targets an endogenous housekeeping gene, such as actin, which is present in all plant samples. Successful amplification of the internal control proves that the DNA quality is sufficient and the PCR reagents are working correctly.

181. (B) Transgene copy number and integration pattern
Standard end-point PCR is a binary detection method that confirms the presence or absence of a target sequence but cannot accurately quantify the amount of DNA. Therefore, it cannot be used to determine the number of transgene copies integrated into the genome or to identify complex integration patterns. More advanced techniques like Southern blotting or qPCR are required for this level of detailed molecular characterization.

182. (A) Both A and R are true and R is the correct explanation of A.
Southern blotting is considered the gold standard for analyzing transgene integration because it provides a clear visual representation of the genomic organization. By using restriction enzymes that cut outside the T-DNA, the resulting hybridization patterns reveal the number of distinct loci where the transgene has inserted. This information is critical for identifying stable, single-copy transgenic lines that are ideal for breeding.

183. (D) Once within T-DNA, outside the probe region
For a Southern blot to accurately reflect the number of integration sites, the genomic DNA is typically digested with a restriction enzyme that cuts the T-DNA construct only once. This ensures that each integration event produces a single, uniquely sized fragment consisting of a portion of the T-DNA and the flanking genomic DNA. The number of resulting bands on the blot then directly corresponds to the number of transgene copies.

184. (A) Alkaline denaturation into single strands
After the DNA fragments are separated by size during gel electrophoresis, they must be denatured before being transferred to the membrane. This is typically done by treating the gel with an alkaline solution, which breaks the hydrogen bonds between the two DNA strands. Denaturation is essential because the labeled probe used in the subsequent hybridization step can only bind to single-stranded DNA targets.

185. (B) Capillary action or electrophoretic transfer
The movement of DNA from the agarose gel onto a stable membrane is the central step of Southern blotting. This is classically achieved through capillary action, where a buffer is drawn through the gel and membrane by absorbent paper. Alternatively, an electric current can be used to drive the DNA from the gel onto the membrane. In both cases, the DNA is permanently fixed in its relative positions.

186. (A) qPCR
Real-time quantitative PCR has become a popular alternative to Southern blotting for estimating transgene copy number. It is faster, requires much less genomic DNA, and is more suitable for high-throughput screening of large populations of primary transformants. By comparing the amplification of the transgene to a known single-copy endogenous gene, researchers can accurately calculate the copy number based on the relative fluorescence levels.

187. (A) Double-stranded RNA-mediated mRNA degradation
Post-transcriptional gene silencing is a common mechanism in plants for controlling over-expressed or multi-copy transgenes. It is triggered by the formation of double-stranded RNA, which is recognized and processed into small interfering

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the transformation process. This includes both the Cas9 gene and any bacterial vector backbone sequences. Confirming the absence of these transgenes is critical for regulatory approval in many countries, where transgene-free edited plants are treated more like conventionally bred varieties.

224. (D) Precise base conversions and small indels
Prime editing is a versatile and precise "search-and-replace" technology that can achieve all possible base-to-base conversions, as well as small insertions and deletions. It works by using a modified Cas9 protein fused to a reverse transcriptase enzyme. Because it does not require double-strand breaks or donor templates, prime editing offers a higher degree of precision and fewer unintended byproducts than traditional CRISPR methods.

225. (A) Guiding complex and providing RT templates
The prime editing guide RNA is a modified sgRNA that contains both a targeting sequence and an extension that acts as a template for reverse transcription. The pegRNA guides the prime editing complex to the target site and then provides the genetic information for the desired edit. This dual role allows for highly controlled and specific modifications to be made directly to the plant's genomic DNA.

226. (A) P-2, Q-4, R-3, S-1
CRISPR technology has been adapted for diverse applications. CRISPRa uses a dead Cas9 fused to an activator to increase gene expression. Base editing employs a Cas9 nickase and a deaminase for point mutations. Cas13 is a specialized nuclease that targets RNA instead of DNA. Precise gene replacement via HDR requires a wild-type nuclease and a donor template. These tools allow for unprecedented control over the plant genome.

227. (A) Pre-assembled Ribonucleoprotein (RNP) complexes
A truly transgene-free method of genome editing involves delivering the Cas9 protein and guide RNA directly into plant cells as a pre-assembled ribonucleoprotein complex. Because no DNA is used in this process, there is no risk of foreign DNA integrating into the genome. This RNP approach is particularly effective for transforming protoplasts and can lead to edited plants that are genetically indistinguishable from natural mutants.

228. (D) Rapid degradation-linked off-target effects
Delivering CRISPR/Cas9 as an RNP complex reduces the risk of off-target effects because the protein and RNA are rapidly degraded by the cell after performing the edit. Unlike plasmid DNA, which can persist and continue to produce the nuclease for several days, RNPs provide only a transient pulse of activity. this short duration minimizes the time available for the complex to bind and cut at unintended genomic sites.

229. (B) Difficulty in whole plant regeneration post-delivery
While CRISPR technology is highly effective at the cellular level, a major bottleneck in applying it to many elite crop varieties is the difficulty of regenerating whole plants from the edited cells. Many high-yielding agricultural lines are recalcitrant to tissue culture and do not respond well to standard transformation protocols. Overcoming these regeneration barriers is essential for the widespread use of genome editing in mainstream crop improvement.

230. (C) Prevention of gene transcriptional initiation
Knocking out the promoter of a gene using CRISPR prevents the transcription machinery from binding and initiating the production of mRNA. As a result, the target gene is effectively silenced, and the corresponding protein is not synthesized. In the case of a ripening gene in tomato, this would lead to a delayed or inhibited ripening phenotype, demonstrating how promoter editing can be used to precisely control plant development.

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160. (D) Excitation by blue or UV light
The fluorescence of GFP is an intrinsic property of the protein that results from its unique three-dimensional structure. To visualize this fluorescence in transformed plant cells, the tissue must be illuminated with light of a specific wavelength, typically in the blue or ultraviolet range. This excitation causes the GFP to emit a bright green light, which can be easily detected using fluorescence microscopy.

161. (A) Exogenous addition of luciferin substrate
The luciferase reporter system is based on bioluminescence, the production of light through a chemical reaction. Unlike GFP, luciferase requires the addition of an external substrate, luciferin, and ATP to produce light. This system is extremely sensitive and allows for the quantitative measurement of gene expression in living tissues, often used to study circadian rhythms and rapid responses to environmental stimuli.

162. (B) II and III
Reporter genes are essential for visualizing gene expression. The GUS assay produces an insoluble blue precipitate through an enzymatic reaction, which is useful for histological studies. The luciferase assay is based on bioluminescence and provides highly sensitive quantitative data. However, GFP requires an external excitation light source to fluoresce; it does not produce light spontaneously, making it a passive rather than an active emitter.

163. (A) Functionality of a promoter construct
Transient expression analysis is a rapid method to test the activity of a gene construct without waiting for the time-consuming process of stable transformation and regeneration. By delivering the DNA into cells via methods like agroinfiltration, researchers can check if a promoter is functional and drives expression of a reporter gene within a few days. This is a critical preliminary step in vector design.

164. (D) Bacteria cannot splice eukaryotic introns
To prevent false-positive signals from Agrobacterium during GUS assays, researchers often insert a eukaryotic intron into the uidA coding sequence. Because bacteria lack the machinery to splice introns, they cannot produce functional GUS protein from this construct. In contrast, plant cells can correctly splice the intron, ensuring that any blue color observed is the result of gene expression within the plant genome.

165. (B) Propulsion of DNA-coated microprojectiles
Biolistics, or particle bombardment, is a physical method of gene transfer that uses high-pressure gas to propel tiny DNA-coated microprojectiles into target tissues. These particles penetrate the cell walls and membranes, delivering the DNA directly into the cytoplasm or nucleus. This vectorless approach is highly versatile and can be used to transform a wide range of species and tissue types, including monocots and organelles.

166. (C) Gold or Tungsten
In biolistics, the microprojectiles used to carry the DNA are typically made of dense, inert metals such as gold or tungsten. These metals have high mass, which gives them the necessary momentum to penetrate plant cell walls, and they are chemically stable, ensuring they do not react with the DNA or harm the plant cells. Gold is often preferred because it is non-toxic and uniform in size.

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167. (D) Calcium chloride and spermidine
To ensure that the DNA is effectively delivered by the microprojectiles, it must be firmly attached to their surface. This is typically achieved by precipitating the DNA onto the gold or tungsten particles using a mixture of calcium chloride and spermidine. These chemicals facilitate the binding of the negatively charged DNA to the metal, creating a stable coating that survives the high-speed propulsion process.

168. (A) Generating transient microscopic membrane pores
Electroporation uses short, high-voltage electrical pulses to create temporary, microscopic pores in the cell membrane. These transient openings allow foreign DNA molecules to enter the cell by diffusion or electrophoretic movement. Once the pulse is removed, the pores close, and the cell can incorporate the new DNA into its genome. This technique is a common method for transforming both bacterial and plant cells.

169. (B) Isolated wall-less protoplasts
While electroporation can be used on some intact tissues, it is most efficient when applied to isolated protoplasts. The absence of the cell wall allows the DNA to move directly to the plasma

(B) mRNA synthesis
(C) Phenotypic plasticity
(D) Phene synergism

2015

10. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A): The central dogma alone is sufficient to perfectly predict an organism's phenome from its genome.
Reason (R): Epigenetic modifications, environmental factors, and post-translational changes significantly influence final phenotypic expression.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2010

11. Which option best classifies the intermediate biological entities between the genome and the phenome?
(A) Transcriptome, proteome, and metabolome
(B) Microbiome, biome, and ecosphere
(C) Morphome, physiome, and biotype
(D) Karyotype, haplotype, and idiogram

2006

12. How does the concept of biological pathways clarify the genome-to-phenome relationship?
(A) It isolates the genotype from phenotypic expression
(B) It shows that single genes act in isolation to produce single traits
(C) It demonstrates that multiple interacting gene products form complex metabolic networks generating traits
(D) It proves that environmental inputs are irrelevant

2012

13. Which statement identifies a correct definition of a "phene" in modern phenomics?
(A) A generalized term for any plant characteristic
(B) A measurable environmental variable
(C) A specific DNA sequence controlling a metabolic pathway
(D) The basic, indivisible building block of a complex trait

2007

14. Identify the INCORRECT pairing of terms and their biological definitions.
(A) Genome - Complete set of DNA in an organism
(B) Phene - Irreducible unit of phenotype
(C) Phenome - The static, unchangeable physical traits of an organism
(D) Transcriptome - The total set of RNA transcripts

2013

15. The concept of a phene is least relevant to which of the following approaches?
(A) Deconstructing complex physiological mechanisms
(B) Counting the total number of chromosomes in a karyotype
(C) Modeling the elementary components of drought tolerance
(D) Dissecting a complex trait into elemental morphological features

2019

16. Why is a phene considered distinct from a complex trait?
(A) A trait is genetically inherited, but a phene is solely environmental
(B) A phene is visible to the naked eye, whereas a trait is not
(C) A phene describes yield, whereas a trait describes cellular structure
(D) A trait is an aggregate of multiple interacting phenes

2024

17. Which of the following best demonstrates the distinction between a phene and a complex trait?
(A) Stomatal density is a phene, while overall drought resilience is a complex trait
(B) Leaf area is a complex trait, while grain yield is a phene
(C) Plant height is a phene, while root hair length is a trait
(D) Photosynthesis rate is a complex trait, while light interception is the only phene

2018

18. What is the consequence of incorrectly treating a complex agricultural trait as a single irreducible phene in genetic mapping?
(A) Increased accuracy in identifying specific causal genes through precise analysis.
(B) Complete elimination of environmental variance within the target population.
(C) Reduced mapping resolution due to

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leaves from the sky using standard visible light sensors.
(D) To avoid interference with commercial aircraft operating at higher altitudes above the agricultural site.

2014

72. Which component is foundational to modern computer vision pipelines designed for high-throughput trait extraction?
(A) Manual tracing of leaves on graph paper
(B) Destructive chemical assays
(C) Image segmentation and feature extraction algorithms
(D) Genetic crossing of segregating populations

2004

73. What role does machine learning primarily play in processing raw phenomic sensor data?
(A) It sequences the DNA of the imaged plants
(B) It physically alters the phenotype to match the desired model
(C) It automates the classification and extraction of complex phenotypic traits from large unstructured datasets
(D) It eliminates the need for any initial ground-truth calibration data

2023

74. Which deep learning architecture is most universally applied for image-based trait extraction, such as disease lesion segmentation?
(A) Support Vector Machines (SVM)
(B) Random Forests
(C) Linear Regression Models
(D) Convolutional Neural Networks (CNN)

2014

75. Identify the correct procedural sequence for extracting a morphological trait from RGB images using a traditional computer vision pipeline.
(A) Feature extraction → Image acquisition → Segmentation → Trait calculation
(B) Image acquisition → Segmentation (background removal) → Feature extraction → Trait calculation
(C) Trait calculation → Feature extraction → Image acquisition → Segmentation
(D) Segmentation → Trait calculation → Image acquisition → Feature extraction

2012

76. How does advanced phenomics specifically enhance Genomic Selection (GS) models?
(A) By completely replacing SNP markers with phenotypic markers
(B) By providing highly accurate, multi-environment trait data that improves the training population's predictive accuracy
(C) By directly editing the genome of the elite cultivars
(D) By ensuring that the environment has zero impact on the predictions

2004

77. What represents a major hurdle in integrating high-throughput phenomic data with genomic models?
(A) Phenomic data sizes are too small to be mathematically modeled
(B) Managing and aligning massive, multi-dimensional, time-series phenotyping datasets with genotypic data
(C) Genotyping platforms are currently slower than phenotyping platforms
(D) Marker-assisted selection fundamentally cannot utilize quantitative data

2008

78. Which concept bridges the integration of phenomics and genomics to accelerate crop improvement?
(A) The "genome-to-phenome" predictive modeling approach
(B) The "phenotyping bottleneck" theory
(C) Destructive end-point sampling
(D) The rejection of quantitative genetics

2002

79. What defines a "phenomic marker" in the context of integrated breeding?
(A) A rapid, non-destructive spectral signature or proxy trait highly correlated with complex physiological performance or yield
(B) A specific DNA sequence
(C) A physical tag placed on a plant in the field
(D) A synthesized chemical used to induce mutations

2002

80. Given below are statements about continuous non-destructive phenotyping:
I. It permits longitudinal studies of trait development.
II. It requires killing the plant at various stages to measure dry weight.
III. It generates time-series data crucial for functional mapping.
IV. It utilizes sensors like RGB and hyperspectral cameras.

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2004

28. Which scenario best illustrates the concept of Genotype by Environment (GxE) interaction?
(A) Cultivar A outyields Cultivar B under drought, but Cultivar B outyields Cultivar A under irrigation
(B) Cultivar A always yields higher than Cultivar B in all tested environments
(C) Both Cultivars A and B show exactly the same yield reduction under heat stress
(D) Yields of all cultivars remain strictly constant regardless of the environment

2022

29. What is a primary consequence of significant GxE interactions in crop breeding programs?
(A) It guarantees uniform crop performance globally
(B) It complicates the selection of broadly adapted varieties
(C) It eliminates the need for multi-environment field trials
(D) It proves that genotype is the sole determinant of phenotype

2022

30. Consider the following statements regarding phenotypic plasticity:
I. It is the ability of a single genotype to produce different phenotypes in response to environmental variation.
II. It is always detrimental to the evolutionary fitness of a crop.
III. It can be graphically represented using reaction norms.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I and III
(C) II and III
(D) I only

2004

31. What term defines the function or curve relating a specific environmental variable to the phenotypic expression of a single genotype?
(A) Reaction norm
(B) Selection differential
(C) Heritability index
(D) Pedigree chart

2001

32. Which feature represents an advantage of high phenotypic plasticity in variable agricultural environments?
(A) Dynamic physiological adjustments, such as stomatal closure, that maintain plant survival.
(B) Reduced capacity for the plant to survive sudden and severe frost during early growth.
(C) Forced acceleration of the plant's internal rate of random genetic mutations under stress.
(D) Realization of a completely uniform yield regardless of the severity of the stress applied.

2006

33. Identify the INCORRECT pair regarding phenotypic variations.
(A) Environmental covariates - Measurable environmental factors like soil moisture
(B) Phenotypic plasticity - Morphological shifts induced by local light conditions
(C) GxE interaction - Differential genetic response to specific stressors
(D) Micro-environmental variations - Broad, regional climate shifts across continents

2021

34. How do micro-environmental variations within a single field affect high-throughput phenotyping data?
(A) They introduce spatial noise requiring statistical correction for accurate assessment.
(B) They standardize the phenotypes of all plants naturally within the specific plot area.
(C) They eliminate phenotypic variance entirely by providing uniform resource distribution.
(D) They make GxE interactions completely unmeasurable across different field locations.

2006

35. Why is monitoring environmental covariates simultaneously with phenotyping critical in modern agriculture?
(A) Because genotypes do not respond to covariates
(B) Because cameras cannot function without covariate data
(C) To reduce the total amount of genetic data required
(D) To isolate the true genetic effect by accounting for environmental variance (V_e)

2004

36. Which factor is most likely categorized as a micro-environmental variation in a greenhouse?
(A) The average seasonal rainfall of the geographical region
(B) Small temperature gradients caused by the positioning of cooling fans

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(B) Pleiotropy
(C) Epistasis
(D) Phene synergism

2001

90. Determine the correct order of data flow in a high-throughput phenotyping platform, then select the matching option.
I. Data Analysis and Trait Extraction
II. Sensor Calibration and Image Acquisition
III. Decision Making and Genomic Prediction
IV. Image Stitching and Pre-processing
(A) I - II - III - IV
(B) II - IV - I - III
(C) IV - II - I - III
(D) II - I - IV - III

2017

91. What describes the mathematical relationship between the heritability of a trait and precise phenotyping?
(A) Precise phenotyping reduces experimental error (V_e), thereby increasing the calculated broad-sense heritability (H^2)
(B) Precise phenotyping increases genotypic variance (V_g) directly
(C) Precise phenotyping decreases heritability by exposing hidden variations
(D) Heritability remains mathematically independent of phenotyping accuracy

2014

92. Which biological phenomenon best illustrates phene synergism in producing grain yield?
(A) The combined, interactive effects of photosynthetic rate, root nitrogen uptake, and sink capacity culminating in final yield
(B) A single gene dictating grain color
(C) The independent segregation of chromosomes during meiosis
(D) The silencing of a trait due to DNA methylation

2018

93. How do researchers validate machine learning models used for automated trait extraction?
(A) By completely ignoring traditional measurements
(B) By comparing the algorithm's output against a subset of highly accurate, manually measured "ground truth" data
(C) By running the model on a different plant species without calibration
(D) By strictly using synthetic computer-generated images

2002

94. What is the significance of the "phenotyping bottleneck" in the era of Next-Generation Sequencing?
(A) We can phenotype faster than we can sequence DNA
(B) We have millions of sequenced genomes, but lack the corresponding high-resolution trait data to understand their function
(C) Field trials are too fast for modern computers to process
(D) The bottleneck only affects model plants, not major crops

2006

95. Identify the correct pair describing a phenotyping paradigm and its typical setting.
(A) "Plants to sensors" - Mobile UAVs flying over massive open fields
(B) "Sensors to plants" - Tractors (phenomobiles) driving over field plots
(C) "Aerial phenomics" - Conveyor belts in a growth chamber
(D) "Destructive sampling" - Continuous daily LiDAR scanning

2013

96. Which index relies on comparing the reflectance of near-infrared (NIR) and red light to estimate vegetation health?
(A) Photochemical Reflectance Index (PRI)
(B) Normalized Difference Vegetation Index (NDVI)
(C) Crop Water Stress Index (CWSI)
(D) Water Deficit Index (WDI)

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2006

97. What defines a pleiotropic effect in the genome-to-phenome relationship?
(A) Multiple genes affecting a single quantitative trait
(B) A single gene simultaneously influencing multiple, distinct phenes
(C) An environmental factor silencing a gene completely
(D) The synergistic interaction of two distinct genomes

2010

98. Why is an accurate measurement of canopy temperature via thermal imaging reliant on understanding micro-environmental variations?
(A) Canopy temperature is solely determined by genetics
(B) Transpiration rates and leaf temperatures fluctuate rapidly with micro-changes in wind

(D) To focus research efforts entirely on simple single-gene Mendelian characteristics.

2019

45. What represents a distinct advantage of non-destructive phenotyping over destructive sampling?
(A) It requires the harvesting and drying of plant material
(B) It allows for the continuous monitoring of developmental trait trajectories over the entire growth cycle
(C) It inherently ignores the effects of the environment
(D) It restricts measurements to the very end of the crop season

2015

46. Identify the correct combination of principles underlying high-throughput phenotyping platforms.
(A) Manual labor, destructive assessment, low frequency
(B) Automation, sensor-based measurement, high spatial and temporal resolution
(C) Visual estimation, isolated environment, single-time-point sampling
(D) Chemical analysis, root excavation, low throughput

2002

47. In the "plants to sensors" paradigm, how is data typically acquired?
(A) Drones fly over stationary fields to capture canopy traits
(B) Tractors equipped with sensors are driven through open fields
(C) Scientists carry portable scanners directly to the field
(D) Plants are grown on automated conveyor belts and transported to central stationary imaging cabinets

2008

48. Which environment is most commonly associated with the "plants to sensors" platform design?
(A) Dryland agricultural fields
(B) Controlled-environment automated greenhouses
(C) Unmanaged natural ecosystems
(D) Deep-water rice paddies

2010

49. What is the main logistical limitation of a "plants to sensors" greenhouse platform?
(A) The artificial environment may not perfectly replicate complex real-world field conditions (GxE limitations)
(B) It completely eliminates the ability to measure growth over time
(C) It requires massive drones to move the plants
(D) It can only measure roots, not shoots

2013

50. Given below are statements regarding the "sensors to plants" paradigm:
I. It involves bringing measurement devices to stationary plants in the field.
II. It includes ground-based phenomobiles and mobile field gantries.
III. It is restricted entirely to controlled indoor environments.
IV. It allows for phenotyping under natural environmental conditions.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) I, II and III
(C) I and IV
(D) II and III

2021

51. What differentiates a mobile field gantry from a standard phenomobile (tractor-based)?
(A) Gantries operate on fixed rails over a specific plot, providing extremely precise spatial repeatability
(B) Gantries are airborne vehicles driven by propellers
(C) Gantries require plants to be brought to them via conveyors
(D) Gantries cannot carry heavy imaging equipment

2017

52. Which statement correctly identifies a ground-based phenotyping vehicle?
(A) An automated greenhouse conveyor belt
(B) A high-clearance tractor retrofitted with multi-sensor arrays (phenomobile)
(C) An Unmanned Aerial Vehicle (UAV)
(D) A stationary laboratory CT scanner

2024

53. What is a prominent advantage of using aerial phenomics platforms (UAVs) over ground-based platforms?
(A) UAVs provide rapid, high-throughput canopy scanning of vast field areas without causing soil compaction
(B) UAVs carry much heavier payload arrays, including heavy X-ray scanners

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(C) UAVs operate perfectly regardless of wind or rain
(D) UAVs offer superior penetration of the soil surface to measure root architecture

2024

54. Which sensor type on a UAV is most likely utilized to assess general crop morphology and canopy cover?
(A) Thermal infrared camera
(B) Ground Penetrating Radar (GPR)
(C) X-ray computed tomography
(D) High-resolution RGB digital camera

2006

55. What structural plant traits are most directly extracted from standard visible-light (RGB) imaging?
(A) Leaf area index, plant height, and architectural geometry
(B) Nitrogen concentration and sucrose content
(C) Stomatal conductance and transpiration rate
(D) Photosystem II efficiency

2005

56. Which spectral range is primarily targeted by multispectral and hyperspectral imaging to assess crop biochemical properties?
(A) X-ray and Gamma-ray wavelengths
(B) Visible to shortwave infrared (VIS-SWIR) spectrum
(C) Ultraviolet C (UV-C) exclusively
(D) Microwave and radio frequencies

2025

57. Identify the correct distinguishing factor between multispectral and hyperspectral imaging.
(A) Multispectral measures temperature; hyperspectral measures biomass volume
(B) Multispectral captures contiguous narrow bands; hyperspectral captures 3 to 10 broad bands
(C) Multispectral is strictly destructive; hyperspectral is non-destructive
(D) Multispectral captures a few broad, discrete bands; hyperspectral captures hundreds of narrow, contiguous spectral bands

2024

58. How do hyperspectral cameras aid in early crop stress detection before symptoms are visible to the naked eye?
(A) By detecting subtle changes in pigment composition and cellular structure via specific reflectance signatures.
(B) By directly and rapidly altering the plant's internal temperature to trigger a visible phenotypic response.
(C) By physically and automatically extracting chlorophyll samples from leaves for instant chemical assessment.
(D) By mapping the 3D structure of the root system to identify underground nutrient deficiencies.

2006

59. Which index, commonly derived from multispectral imaging, is a standard proxy for plant vigor and green biomass?
(A) Water Deficit Index (WDI)
(B) Normalized Difference Vegetation Index (NDVI)
(C) Photochemical Reflectance Index (PRI)
(D) Crop Water Stress Index (CWSI)

2010

60. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A): Thermal infrared imaging is highly effective for evaluating plant water deficit.
Reason (R): Water-stressed plants close their stomata, reducing transpirational cooling, which subsequently raises canopy temperature.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2009

61. What physiological parameter is indirectly measured using thermal infrared imaging?
(A) Stomatal conductance
(B) Lignin content
(C) Root elongation rate
(D) Photosynthetic electron transport

2010

62. Which environmental covariate is absolutely critical to record simultaneously when capturing thermal infrared images of a crop canopy?
(A) Soil pH
(B) Ambient air temperature and vapor pressure deficit (VPD)
(C) Magnetic field strength
(D) Lunar phase

NODIA

2012

63. Chlorophyll fluorescence imaging is fundamentally used to non-invasively assess which plant mechanism?
(A) Structural rigidity of the cell wall
(B) Efficiency of Photosystem II and electron transport chain dynamics
(C) Water transport in the xylem
(D) Root nodule formation

2006

64. What specific metric, calculated via chlorophyll fluorescence, indicates the maximum quantum efficiency of Photosystem II?
(A) $\frac{F_v}{F_m}$
(B) $\frac{R_s}{R_n}$
(C) $V_{\{}\max_{\}}$
(D) LAI

2001

65. Why is chlorophyll fluorescence imaging particularly advantageous for early disease detection?
(A) It captures the physical shape of fungal spores on the leaf.
(B) It measures the heat emitted by the disease-causing bacteria.
(C) It completely sterilizes the leaf surface using intense light.
(D) Pathogens alter photosynthetic metabolism before visible lesions appear.

2007

66. Which technology utilizes pulsed laser beams to measure the distance to a target and reconstruct 3D models of plant architecture?
(A) RGB stereovision
(B) Thermal thermography
(C) Hyperspectral radiometry
(D) LiDAR (Light Detection and Ranging)

2016

67. What are the primary structural traits estimated using terrestrial LiDAR in field phenotyping?
(A) Plant biomass, canopy volume, and 3D architectural traits
(B) Chlorophyll a/b ratio and carotenoid levels
(C) Deep soil moisture and root architecture
(D) Leaf surface temperature gradients

2018

68. Which feature makes LiDAR distinctively powerful compared to standard 2D RGB imaging for dense crop canopies?
(A) Laser pulses partially penetrate canopy gaps to generate a comprehensive 3D point cloud of internal structure.
(B) LiDAR relies purely on natural sunlight for the illumination of the target during high speed scanning.
(C) LiDAR captures spectral reflectance across hundreds of narrow bands to assess chemical composition.
(D) LiDAR is completely immune to any wind movements during the process of field scanning.

NODIA

2011

69. How does high temporal resolution in phenotyping advance crop modeling?
(A) It enables the tracking of dynamic growth curves, phenology, and developmental transitions over the growth cycle
(B) It restricts data to a single harvest timepoint
(C) It maps the 3D structure with millimeter precision
(D) It limits analysis to post-harvest grain quality

2023

70. Match the sensor technology in List I with its primary phenotypic application in List II.
List I: (Sensor Technology)
P. Thermal Infrared
Q. LiDAR
R. Chlorophyll Fluorescence
S. Hyperspectral Imaging
List II: (Primary Application)
1. 3D plant architecture and biomass
2. Canopy temperature and water stress
3. Biochemical composition and pigment signatures
4. Photosynthetic efficiency and early stress detection
(A) P-1, Q-2, R-3, S-4
(B) P-2, Q-1, R-4, S-3
(C) P-3, Q-4, R-1, S-2
(D) P-4, Q-3, R-2, S-1

2022

71. Why is adequate spatial resolution critical when deploying UAVs for field phenotyping?
(A) To separate individual plant organs from background soil and shadow pixels within the captured imagery.
(B) To ensure the drone flies fast enough to cover the entire field area within a limited battery lifespan.
(C) To measure the internal cellular structure of

compounding multiple distinct genetic controls.
(D) Perfect alignment of QTLs with metabolic pathways across several generations.

2018

19. Based on anatomical distinctions, which of the following represents a phene rather than a composite trait?
(A) Xylem vessel diameter
(B) Total shoot biomass
(C) Final crop yield
(D) Canopy architecture

2018

20. Match the term in List I with its correct characteristic in List II.
List I: (Terms)
P. Genotype
Q. Phenome
R. Phene
S. Complex Trait
List II: (Characteristics)
1. The sum of all expressed phenotypes
2. The organism's genetic composition
3. An aggregate outcome of multiple biological processes
4. An elementary, irreducible observable unit
(A) P-1, Q-2, R-3, S-4
(B) P-2, Q-1, R-4, S-3
(C) P-3, Q-4, R-1, S-2
(D) P-4, Q-3, R-2, S-1

2021

21. What describes phene synergism in the context of plant biology?
(A) The antagonistic effect of two alleles at the same genetic locus.
(B) The interaction of distinct phenes producing a non-additive emergent trait.
(C) The direct linear addition of single gene effects on total biomass.
(D) The masking of one phene by the dominant expression of another trait.

2013

22. Which genetic concept describes a single gene influencing multiple, seemingly unrelated phenes?
(A) Epistasis
(B) Polygenic inheritance
(C) Pleiotropy
(D) Genetic linkage

2003

23. What emergent property arises from the pleiotropic effects of a gene regulating root architecture?
(A) The gene independently controls flower color
(B) The gene alters both water uptake efficiency and nutrient acquisition simultaneously
(C) The gene strictly limits its effect to the exact locus of expression
(D) The gene eliminates the need for environmental adaptation

2015

24. Identify the correct statement regarding emergent macroscopic phenotypes.
(A) They are entirely determined by the expression of a single dominant physiological phene.
(B) They represent phenomena completely isolated from the organism's underlying genotype.
(C) They result from the complex synergistic interaction of numerous elementary phenes.
(D) They are purely artifacts of measurement error during large scale field evaluations.

2009

25. Which statement represents the best example of a macroscopic emergent phenotype in agriculture?
(A) The specific angle of a single lateral root
(B) The total harvestable grain yield of a wheat field
(C) The length of a specific internode
(D) The density of trichomes on a leaf surface

2017

26. In the fundamental quantitative genetics equation $V_p = V_g + V_e + V_{\{\geq\}}$, what does $V_{\{\geq\}}$ represent?
(A) Variance due to general environment
(B) Variance resulting from the interaction between genotype and environment
(C) Variance due to genotypic error
(D) Variance associated with genetic epistasis

2024

27. According to quantitative genetics, if an environment is perfectly uniform ($V_e = 0$) and there is no GxE interaction, what dictates phenotypic variance (V_p)?
(A) Environmental plasticity
(B) Phenotyping error
(C) The reaction norm
(D) Genotypic variance (V_g)

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V. It completely resolves the issue of GxE interactions.

Which of the above statement(s) is/are INCORRECT?

(A) I, II and IV
(B) II and V
(C) I, III and IV
(D) III, IV and V

2004

81. In Marker-Assisted Selection (MAS), how does improved phenotyping resolution impact the discovery of markers?

(A) It improves the phenotypic precision, thereby increasing the statistical power to detect tight linkages between markers and QTLs
(B) It decreases the LOD score of true markers
(C) It causes major effect QTLs to behave like minor effect QTLs
(D) It renders MAS completely obsolete

2015

82. Which of the following best describes the transition from classical to Next-Generation Phenotyping?

(A) Moving from quantitative measurements to purely qualitative visual scores
(B) Moving from single-point, labor-intensive manual assessments to automated, multi-dimensional, continuous monitoring
(C) Moving from field assessments to exclusively in-vitro lab assessments
(D) Moving from multispectral cameras back to the human eye

2016

83. Why is defining a "phene" crucial for the mathematical modeling of biological pathways?

(A) It allows complex traits to be parameterized as a network of basic, independent physiological or anatomical inputs
(B) It creates a highly complex, inseparable variable
(C) It ensures that the model ignores genetic variation
(D) It prevents the use of computational algorithms

2015

84. Which statement about the term "phenome" is factually correct?

(A) It was coined before the term "genome"
(B) It encompasses the entirety of traits, from molecular profiles (metabolites) to macroscopic structures (yield)
(C) It describes only traits that are visible without instrumentation
(D) It is an entirely theoretical concept that cannot be measured

2018

85. How do varying agricultural environments affect the expression of a specific genotype?

(A) They trigger differential gene expression, resulting in phenotypic plasticity
(B) They alter the underlying DNA sequence permanently
(C) They have no impact unless the plant is a hybrid
(D) They eliminate the concept of herizability

2025

86. Which application is least relevant to the deployment of unmanned aerial vehicles (UAVs) in agriculture?

(A) High-throughput scanning of experimental breeding plots
(B) Precision application of localized water stress in a controlled greenhouse
(C) Field-scale mapping of crop spatial variability
(D) Temporal monitoring of canopy development across a season

2012

87. In the context of aerial phenomics, what does the term "orthomosaic" refer to?

(A) A composite, geometrically corrected image created by stitching together multiple UAV-captured aerial photos
(B) A genetic map of overlapping QTLs
(C) A specific type of thermal sensor
(D) The pattern of leaf arrangement on a stem

2018

88. What is the fundamental limitation of using standard RGB imaging alone for crop stress detection?

(A) It primarily captures visible symptoms (like chlorosis), often missing early pre-symptomatic physiological stress
(B) It requires highly expensive, specialized radioactive sensors
(C) It cannot accurately measure plant height
(D) It operates outside the visible light spectrum

2017

89. Which concept explains why a high-yielding genotype in a temperate climate may fail in a tropical climate?

(A) Genotype by Environment (GxE) interaction

NODIA

(C) The specific global latitude of the greenhouse facility
(D) The total photoperiod duration expected for the season

2014

37. What fundamental discrepancy characterizes the "phenotyping bottleneck"?
(A) The inability to extract any DNA from plant tissues rapidly
(B) The gap between high-speed, low-cost genomic sequencing and slow, labor-intensive trait evaluation
(C) The speed of manual harvesting compared to automated harvesting
(D) The high cost of microarrays versus the low cost of field labor

2014

38. Which technological advancement directly caused the phenotyping bottleneck to become a prominent issue in plant science?
(A) The widespread adoption of Next-Generation Sequencing (NGS)
(B) The invention of the light microscope
(C) The development of the first hybrid corn varieties
(D) The use of traditional destructive biomass sampling

2002

39. What is a major disadvantage of traditional, conventional field phenotyping methods?
(A) They generate an overwhelming amount of hyperspectral data
(B) They are entirely independent of weather conditions
(C) They often require destructive sampling, preventing temporal time-series analysis on the same plant
(D) They rely too heavily on artificial intelligence algorithms

2010

40. Choose the correct sequence of technological evolution in plant evaluation.
(A) High-throughput phenomics → Visual manual scoring → Destructive sampling
(B) Visual manual scoring → Destructive sampling → High-throughput non-destructive phenotyping
(C) Destructive sampling → High-throughput non-destructive phenotyping → Visual manual scoring
(D) High-throughput non-destructive phenotyping → Destructive sampling → Visual manual scoring

2005

41. How does the limitation of scale impact conventional phenotyping in modern breeding?
(A) It restricts breeders to evaluating only thousands of lines instead of millions, reducing selection intensity
(B) It forces the plants to grow smaller than their genetic potential
(C) It eliminates the need for multi-location trials
(D) It increases the mutation rate of the crop populations

2008

42. What effect do traditional phenotyping inaccuracies have on Quantitative Trait Locus (QTL) mapping?
(A) Decreased resolution, leading to broader QTL intervals and missing minor loci.
(B) Artificially increased statistical power for the identification of mapping loci.
(C) Direct alteration of the actual DNA sequence found in the mapping population.
(D) Transformation of all complex QTLs into perfectly simple Mendelian traits.

2012

43. Why is precise phenotyping specifically crucial for the success of Genome-Wide Association Studies (GWAS)?
(A) GWAS relies on exact trait associations; high error leads to false negatives and positives.
(B) GWAS algorithms possess the inherent ability to correct for all phenotypic inaccuracies.
(C) GWAS only utilizes qualitative traits, which are completely immune to phenotyping errors.
(D) Accurate phenotyping significantly reduces the number of SNPs required for whole sequencing.

2012

44. Which of the following best defines the primary objective of Next-Generation Phenotyping (High-Throughput Phenotyping)?
(A) To automate and scale the capture of accurate, multi-dimensional trait data non-destructively.
(B) To strictly replace all existing genomic sequencing methods with visual sensors.
(C) To increase the total manual labor required for comprehensive field assessments.

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speed and local humidity
(C) Thermal cameras generate their own heat that masks micro-environments
(D) Micro-environments prevent stomata from opening entirely

2012

99. Which of the following represents an inference based on the principles of GxE interactions?
(A) A variety bred in an optimal greenhouse will always underperform in the field
(B) To ensure field resilience, a crop must be phenotyped across multiple target environments, not just one location
(C) The genome has no influence on field performance
(D) GxE interactions only occur in polyploid plants

2004

100. Given below are statements about LiDAR technology in phenomics:
I. It generates a 3D point cloud representing plant architecture.
II. It is fundamentally a passive sensor relying on solar illumination.
III. It can precisely measure plant height and estimate biomass non-destructively.
Which of the above statement(s) is/are correct?
(A) I and III
(B) II and III
(C) I and II
(D) II only

2007

101. What is the primary biological meaning of a reaction norm?
(A) The mathematical profile of phenotypic states produced by a single genotype across an environmental gradient
(B) The rate at which a plant mutates under stress
(C) The chemical reaction of a plant to a specific herbicide
(D) The strict threshold at which a plant dies from heat

2015

102. Which trait is typically characterized as highly plastic?
(A) The number of cotyledons in a dicot
(B) The basic floral architecture of an angiosperm
(C) Tillering capacity in wheat under varying plant densities
(D) The ploidy level of somatic cells

2007

103. In the context of computer vision pipelines, what does "image segmentation" specifically achieve?
(A) It sequences the DNA of the plant
(B) It predicts the final grain yield directly
(C) It separates the plant pixels from the background pixels
(D) It alters the wavelength captured by the camera

2015

104. What is a key disadvantage of greenhouse-based "plants to sensors" phenotyping platforms?
(A) They provide excessive spatial resolution
(B) They eliminate manual labor entirely
(C) They cannot utilize RGB cameras due to artificial lighting
(D) Greenhouse environments fail to capture authentic, complex field-based GxE interactions

2022

105. How do environmental covariates assist in modeling phenotypic data?
(A) They act as independent inputs that help mathematically account for non-genetic variance in trait expression
(B) They serve as the dependent variable in genomic predictions
(C) They replace the need for genotyping entirely
(D) They physically block GxE interactions

2011

106. Identify the INCORRECT statement regarding the application of UAVs in phenomics.
(A) UAVs can rapidly image large populations to measure canopy cover
(B) UAV imaging must account for wind and lighting conditions during flight
(C) UAVs are typically equipped with root-excavating sensors to map deep root architecture
(D) UAVs require Ground Control Points (GCPs) or RTK-GPS for precise spatial mapping

NODIA

2005

107. What physiological change is directly linked to the early pre-symptomatic detection of pathogen infection via chlorophyll fluorescence?
(A) A sudden increase in physical leaf thickness
(B) A uniform decrease in overall canopy temperature
(C) A localized drop in Photosystem II operating efficiency ($\frac{F_v}{F_m}$) at the infection site
(D) The immediate appearance of macroscopic

2007

160. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A): Deep learning algorithms, such as Convolutional Neural Networks, are widely used in modern phenomics.
Reason (R): They are highly effective at automatically identifying complex spatial patterns and features in massive, unstructured image datasets.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2024

161. Which biological process is most precisely measured using chlorophyll fluorescence imaging?
(A) Electron transport rate and photosynthetic efficiency of Photosystem II
(B) Total root biomass accumulation
(C) Lignin biosynthesis in the stem
(D) Stomatal density on the abaxial leaf surface

2006

162. How does precise phenomic data specifically benefit Genome-Wide Association Studies (GWAS)?
(A) It mathematically forces all SNPs to show significant linkage
(B) It sharply reduces phenotypic background noise, increasing the statistical power to detect true associations between markers and traits
(C) It completely removes the need for genotypic SNP data
(D) It prevents polygenic traits from expressing

2025

163. What is a known consequence of phene synergism?
(A) Total trait value equals the exact simple addition of individual gene effects
(B) Elementary physiological phenes interact to produce complex macroscopic phenotypes that cannot be easily predicted by studying each phene in isolation
(C) The genome stops transcribing RNA
(D) All environmental variations are mathematically nullified

2013

164. Which of the following is essentially captured by terrestrial LiDAR systems?
(A) Chlorophyll a/b ratios
(B) High-resolution 3D geometrical structure and volume of the crop canopy
(C) Specific soil nutrient levels
(D) Microscopic viral pathogen signatures

2001

165. What fundamental issue is represented by the formula $V_{\{\geq\}}$?
(A) The variance introduced by genetic sequencing errors
(B) The specific variance arising when different genotypes respond differently to the same environmental changes
(C) The total environmental variance in a perfectly uniform field
(D) The simple sum of genetic and environmental variances

2003

166. Identify the correct pair representing a sensor and its primary target trait.
(A) Thermal Camera - Stomatal conductance proxy
(B) RGB Camera - Sub-surface root architecture
(C) LiDAR - Internal cellular biochemistry
(D) Chlorophyll Fluorometer - Canopy structural volume

2025

167. Which of the following statements demonstrates phenotypic plasticity?
(A) A wheat variety consistently produces red grain across all climates
(B) A specific rice genotype dramatically increases its root depth exclusively under severe water deficit conditions
(C) Two different corn hybrids show identical yields in an optimal environment
(D) A genetic mutation physically alters the DNA sequence in response to heat

2018

168. How does tracking spatial and temporal resolution enhance modern crop phenotyping?
(A) It strictly eliminates the need for mathematical modeling
(B) It captures exactly where within a field, and precisely when during the growth cycle, critical physiological changes occur
(C) It forces researchers to rely solely on destructive end-of-season yield data
(D) It prevents drones from utilizing multispectral

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cameras
(C) Phenomobiles are fundamentally incapable of moving through a field
(D) Phenomobiles cause soil compaction and have lower spatial repeatability than gantries

2023

117. Which statement effectively describes the concept of a phenome?
(A) The multidimensional space encompassing all measurable phenotypic traits of an organism
(B) The exact sequence of nucleotides in an organism's nucleus
(C) The theoretical limit of a plant's environmental adaptation
(D) The specific environment in which a plant is cultivated

2025

118. What represents the most significant advantage of non-destructive imaging over destructive sampling for studying drought response?
(A) The ability to dry and accurately weigh the precise water content of the roots
(B) The elimination of the need for advanced statistical analysis
(C) The capacity to track individual plant physiological changes dynamically throughout stress and recovery
(D) The ability to completely isolate the plant from environmental covariates

2015

119. How does phenotypic plasticity complicate the bridging of the genome-to-phenome gap?
(A) It proves that genes do not control phenotypes
(B) It causes a single genotype to produce multiple distinct phenotypes depending on the specific environmental context
(C) It strictly stabilizes the phenotype regardless of the environment
(D) It ensures that the central dogma operates in reverse

2015

120. Match the data analysis or imaging concept in List I with its description in List II.
List I: (Concepts)
P. Image Segmentation
Q. Ground Truthing
R. Point Cloud
S. Reaction Norm
List II: (Descriptions)
1. The 3D data output generated by LiDAR scanning
2. Manual physical measurements used to calibrate and validate sensor models
3. A curve mapping phenotypic expression across an environmental gradient
4. Separating plant pixels from background in digital images
(A) P-1, Q-2, R-3, S-4
(B) P-4, Q-2, R-1, S-3
(C) P-3, Q-4, R-1, S-2
(D) P-2, Q-3, R-4, S-1

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2007

121. What is the fundamental mechanism by which a thermal infrared camera assesses water deficit in a crop?
(A) It measures the physical shrinking of leaves
(B) It detects the reduction in transpirational cooling caused by stomatal closure
(C) It directly visualizes the amount of liquid water inside the xylem
(D) It records the change in leaf color from green to yellow

2006

122. Which is a characteristic application of deep learning in modern plant phenomics?
(A) Randomly generating new DNA sequences
(B) Automating the counting of wheat spikes from complex UAV field images using Convolutional Neural Networks
(C) Manually measuring plant height with a ruler
(D) Physically crossing two distinct parent lines in a greenhouse

2002

123. What does spatial resolution fundamentally determine in aerial crop phenotyping?
(A) The frequency at which the field is flown over a season
(B) The specific wavelengths of light absorbed by the sensor
(C) The size of the smallest detectable feature
(D) The total weight of the camera payload

2012

124. Which scenario best exemplifies the discrepancy addressed by the "phenotyping bottleneck"?
(A) Harvesting the field is faster than planting the field
(B) Artificial intelligence processes images slower than a human
(C) Plants grow faster in a greenhouse than in a

(A) Using the reflectance values of near-infrared (NIR) and red light: $\frac{NIR - Red}{NIR + Red}$
(B) By subtracting the blue band from the thermal band
(C) By calculating the exact ratio of Photosystem II efficiency
(D) By mapping the 3D point cloud volume using LiDAR

2019

178. What is the fundamental distinction between a genotype and a phenome?
(A) Genotype fluctuates dynamically daily; phenome remains completely static from birth
(B) Genotype refers only to RNA; phenome refers exclusively to DNA
(C) They are entirely synonymous terms in modern biology
(D) Genotype is the inherent genetic instructions; phenome is the total observable expression across environments

2002

179. Which concept explains the difficulty in pinpointing specific genes responsible for complex traits like yield?
(A) The traits are highly polygenic and heavily influenced by complex GxE interactions and phene synergism
(B) Complete environmental uniformity
(C) The central dogma of molecular biology is fundamentally false in plants
(D) The complete absence of pleiotropic effects in the genome

2012

180. Given below are statements about early disease detection:
I. It can be achieved using chlorophyll fluorescence before visible lesions form.
II. It is strictly dependent on observing macroscopic necrosis via RGB cameras.
III. It relies on detecting localized disruptions in photosynthetic efficiency.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I and III
(C) II and III
(D) I only

2011

181. What defines an independent biological pathway connecting genome to phenome?
(A) A sequence of localized environmental weather events
(B) A specific, interacting cascade of molecular events executing a distinct biological function
(C) A physical track used by phenomobiles in the field
(D) The direct conversion of DNA directly into structural biomass without RNA

2011

182. Which specific methodology represents a "destructive" phenotyping approach?
(A) Scanning a field with a UAV-mounted multispectral camera
(B) Uprooting a plant, washing its roots, drying it in an oven, and weighing its total biomass
(C) Continuously capturing thermal images of a canopy throughout a day
(D) Measuring chlorophyll fluorescence with a portable fluorometer

2010

183. Identify an advantage of using ground-based mobile field gantries.
(A) They can rapidly cover massive, thousands-of-hectare commercial fields in hours
(B) They provide near-perfect spatial repeatability, scanning the exact same micro-coordinate over the growing season
(C) They are completely unaffected by the need for physical rails or tracks
(D) They rely strictly on satellite imagery

2025

184. What happens when high-resolution phenotyping data replaces low-quality data in a QTL mapping study?
(A) The genetic linkage map becomes completely randomized
(B) The actual physical distance between genes on the chromosome changes
(C) GxE interactions are completely physically eliminated
(D) Noise drops, shrinking QTL intervals and identifying previously masked minor QTLs

2011

185. Which environmental variable represents a micro-environmental variation in an open field plot?
(A) The general macro-climate zone of the continent
(B) Minor localized depressions in soil topography causing uneven water pooling
(C) The total solar radiation expected for that

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allele
(B) It is a macroscopic emergent phenotype resulting from the synergistic interaction of numerous elementary phenes like root depth and stomatal control
(C) It is entirely independent of phenotypic plasticity
(D) It is an irreducible trait that cannot be mathematically modeled

2025

134. Which phenomenon occurs when a single genetic locus influences both root hair length and floral initiation time?
(A) Phene synergism
(B) Pleiotropy
(C) Epistasis
(D) Polyploidy

2008

135. Identify the INCORRECT statement regarding the application of LiDAR in phenomics.
(A) It directly measures internal cellular chlorophyll content
(B) It generates highly accurate 3D point clouds of crop architecture
(C) It relies on emitting laser pulses and measuring the time of flight of the reflected light
(D) It can estimate canopy height and biomass non-destructively

2025

136. What defines an environmental covariate in the context of high-throughput field phenotyping?
(A) A secondary genetic mutation
(B) A measured variable like temperature or soil moisture used to account for environmental variance
(C) The specific software used to segment an image
(D) A destructive method of measuring biomass

2023

137. Why is micro-environmental variations a significant challenge in field phenotyping?
(A) Because they completely halt plant growth
(B) Localized changes in soil can cause phenotypic variations that mask genetic differences.
(C) Because they prevent aerial drones from taking off
(D) Because they render all multispectral cameras blind

2006

138. How does accurate high-throughput phenotyping fundamentally improve QTL mapping?
(A) It ensures that every plant has the exact same phenotype
(B) It minimizes the experimental error variance (V_e), allowing for the statistically robust identification of smaller-effect genomic loci
(C) It actively edits the genome to match the required traits
(D) It eliminates the need for calculating genetic recombination rates

2025

139. Which optical technique is best suited to track the dynamics of Photosystem II operating efficiency over time?
(A) RGB stereovision
(B) Thermal infrared thermography
(C) Chlorophyll fluorescence imaging
(D) Terrestrial LiDAR scanning

2001

140. Choose the correct sequence of hierarchical biological organization linking the genome to macroscopic agricultural traits.
(A) Genome → Emergent Complex Trait → Fundamental Phene → Proteome
(B) Genome → Proteome → Fundamental Phene → Emergent Complex Trait
(C) Proteome → Genome → Emergent Complex Trait → Fundamental Phene
(D) Fundamental Phene → Proteome → Genome → Emergent Complex Trait

2023

141. What is the fundamental advantage of utilizing Genomic Selection (GS) over traditional Marker-Assisted Selection (MAS) in complex trait breeding?
(A) GS relies entirely on single major-effect QTLs
(B) GS uses genome-wide markers to predict breeding values for polygenic traits, using phenomic data for training.
(C) GS requires absolutely no phenotypic data at any stage
(D) GS is restricted strictly to visual qualitative traits

2007

142. Which metric, extracted from RGB images, provides a proxy for understanding light interception capacity in a crop?
(A) Root nodule count
(B) Leaf Area Index (LAI) or canopy cover

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brown lesions

2015

108. Which methodology exemplifies the elimination-based approach to defining a phene?
(A) Adding complex environmental variables to a model until it breaks
(B) Genetically dissecting a complex trait into smaller components until a fundamental unit is isolated
(C) Ignoring molecular mechanisms to focus only on total crop yield
(D) Destroying the entire crop to weigh the dry biomass

2004

109. What fundamentally limits the capacity of conventional phenotyping to keep pace with NGS speeds?
(A) NGS produces data that cannot be mathematically correlated with traits
(B) Conventional phenotyping utilizes highly complex supercomputers that are slow
(C) Traditional tools completely destroy the DNA of the plant
(D) Conventional phenotyping is manual and severely limited in daily throughput

2024

110. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A): High-throughput phenotyping platforms completely eliminate the existence of phenotypic error (V_e).
Reason (R): Automated sensors can objectively measure traits, but micro-environmental fluctuations and sensor noise still introduce experimental variance.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2002

111. Which integration strategy utilizes both dense genome-wide SNP markers and comprehensive high-throughput phenomic data to estimate breeding values?
(A) Traditional Pedigree Selection
(B) Genomic Selection (GS)
(C) Mass Selection
(D) Pureline Selection

2007

112. Why is hyperspectral imaging better suited for detecting subtle biochemical changes than RGB imaging?
(A) It records continuous reflectance across hundreds of narrow bands, capturing specific pigment features
(B) It relies solely on the three visible light bands (Red, Green, Blue)
(C) It inherently measures the temperature of the canopy
(D) It completely penetrates the plant canopy to view roots

2003

113. What is an expected outcome of using highly accurate phenotypic data in a Genome-Wide Association Study (GWAS)?
(A) A decrease in statistical significance for true trait-associated SNPs
(B) A requirement to use fewer genetic markers
(C) The complete suppression of GxE interactions in the dataset
(D) The identification of novel, minor-effect alleles due to reduced background noise

NODIA

2019

114. Which concept describes the situation where several independent phenes interact to produce an outcome greater than the sum of their individual effects?
(A) Additive genetic variance
(B) Phenotypic plasticity
(C) Phene synergism
(D) Mendelian segregation

2021

115. Identify the correct statement characterizing the "sensors to plants" field phenotyping paradigm.
(A) It strictly involves growing plants in pots on conveyor belts
(B) It relies exclusively on destructive biomass harvesting
(C) It aims to capture phenotypic expression in authentic agronomic field environments using mobile sensor platforms
(D) It requires uprooting plants and transporting them to a central laboratory

2001

116. What is a primary limitation of using a high-clearance phenomobile (tractor) compared to a mobile field gantry?
(A) Phenomobiles offer much lower payload capacity
(B) Phenomobiles cannot carry multispectral

2021

151. Why is the concept of a phene more scientifically rigorous than evaluating a generic "trait" for biological modeling?
(A) Phenes are always controlled by entirely distinct, single chromosomes
(B) A phene isolates an indivisible physiological or anatomical mechanism, reducing the confounding effects found in aggregated complex traits
(C) Phenes completely ignore the influence of the environment
(D) Traits can only be measured manually, while phenes can only be measured by drones

2015

152. Which imaging technique relies fundamentally on capturing the reflectance of electromagnetic radiation beyond the human visual spectrum to detect water content and cellular structure?
(A) Multispectral and hyperspectral imaging
(B) Standard RGB digital photography
(C) Traditional visual manual scoring
(D) X-ray crystallography

2008

153. What does the variable V_g stand for in the phenotypic variance equation $V_p = V_g + V_e + V_{\{\geq\}}$?
(A) Gross variation
(B) Genotypic variance
(C) General environment
(D) Geometric volume

2002

154. How do high-throughput phenotyping (HTP) platforms directly address the limitations of visual manual scoring?
(A) By replacing subjective human estimations with objective, highly repeatable, quantitative sensor-derived data
(B) By increasing the time it takes to evaluate a single experimental plot
(C) By focusing exclusively on subjective aesthetic traits like flower color
(D) By strictly limiting evaluations to the end-of-season harvest

2008

155. Which of the following is an example of an application of the "sensors to plants" paradigm?
(A) Potted plants moving via automated tracks into a central imaging chamber
(B) A high-clearance phenomobile driving over stationary field plots to capture hyperspectral canopy data
(C) Harvesting whole plants to extract genomic DNA in the lab
(D) Using a mass spectrometer on ground root tissue

2016

156. What distinguishes a mobile field gantry from UAV aerial phenotyping?
(A) Gantries offer near-perfect temporal repeatability over the exact same sub-millimeter spatial coordinate, whereas UAVs are subject to flight path variations
(B) Gantries operate purely in the upper atmosphere
(C) UAVs can carry significantly heavier sensor payloads than massive steel gantries
(D) Gantries are entirely restricted to indoor greenhouses

2018

157. Which environmental factor does a reaction norm fundamentally graphically represent?
(A) The physical map of a chromosome
(B) The specific response trajectory of a distinct genotype's phenotype across a gradient of environmental conditions
(C) The speed of Next-Generation Sequencing
(D) The physical pathway of water moving through the xylem

2010

158. Identify the INCORRECT assumption regarding the pathway from genome to phenome.
(A) It involves transcription, translation, and post-translational modification
(B) It forms complex metabolic networks
(C) It ultimately dictates the fundamental phenes that synergistically form complex traits
(D) It operates in a vacuum, entirely independent of environmental feedback and epigenetics

2019

159. What specific data does image segmentation aim to isolate when analyzing a drone image of an agricultural field?
(A) Identifying specific DNA sequences in the soil
(B) Separating the pixels representing crop canopy from those representing background soil, shadows, and weeds
(C) Extracting the thermal signatures of the tractor exhaust
(D) Reconstructing the 3D root architecture

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percentage
(C) Stem lignin content
(D) Stomatal aperture size

2008

143. What issue arises when traditional destructive sampling is the sole method used to evaluate crop growth curves?
(A) The data is perfectly continuous and error-free
(B) Growth curves must be inferred from different individuals killed at different timepoints, introducing immense individual-to-individual variance
(C) The plants grow significantly faster due to the sampling process
(D) It becomes impossible to extract DNA from the plants

2009

144. Which statement characterizes a "phenomic pipeline"?
(A) A physical tube used to irrigate the crops automatically
(B) The sequential computational workflow that acquires raw sensor data, processes it, and extracts quantifiable biological metrics
(C) The physiological channel through which nutrients move from root to shoot
(D) A theoretical model completely devoid of mathematical algorithms

2012

145. What is the primary purpose of an Unmanned Aerial Vehicle (UAV) in modern field phenomics?
(A) To act as a dynamic platform carrying specialized sensors for rapid, high-throughput spatial phenotyping at the canopy level
(B) To completely replace all ground-based soil sampling
(C) To strictly apply precise doses of chemical fertilizers
(D) To manually pollinate specific experimental breeding plots

2018

146. How does thermal infrared imaging assist in identifying drought-tolerant genotypes?
(A) Tolerant genotypes maintain transpiration to keep canopies cool under stress.
(B) Tolerant genotypes generate internal metabolic heat to survive seasonal drought.
(C) Susceptible genotypes reflect specific visible green light spectra to reduce heat.
(D) Thermal imaging identifies the exact genetic sequence coding for drought resilience.

NODIA

2018

147. Identify a major cause of the "phenotyping bottleneck."
(A) High-throughput sequencing technologies are too expensive compared to field labor
(B) The lack of high-throughput, accurate, and cost-effective methods to evaluate complex plant traits at the scale of genomic data generation
(C) The overabundance of human experts capable of manual visual scoring
(D) The inability of plants to express genetic variation in field conditions

2017

148. Which term defines the ability of a genotype to produce multiple phenotypes depending strictly on the environment?
(A) Phenotypic plasticity
(B) Epigenetic silencing
(C) Genetic bottleneck
(D) Chromosomal crossover

2007

149. What is a "phene" according to the definitions established in phenomics?
(A) A generalized visible characteristic like total plant yield
(B) The fundamental, elementary unit of a biological phenotype
(C) A unit of genetic recombination
(D) An environmental stressor affecting the plant

2003

150. Given below are statements about Genotype by Environment (GxE) interaction:
I. It means that the best genotype in one environment may not be the best in another.
II. It complicates the broad adaptability of new crop varieties.
III. It can be mathematically modeled using multi-location trial data.
IV. It proves that genotypes are immune to environmental changes.
V. It highlights the importance of localized environmental covariates.
Which of the above statement(s) is/are INCORRECT?
(A) I, II, III and V
(B) IV only
(C) I, III and V
(D) II, IV and V

sensors

2024

169. What is the fundamental goal of integrating phenomics with genomic selection (GS)?
(A) To abandon the use of DNA sequencing entirely
(B) To improve breeding value predictions for complex traits by training models with high-dimensional, precise environmental data
(C) To isolate plant breeding from computational science
(D) To ensure that environmental variance strictly dictates plant selection

2016

170. Match the phenotyping approach in List I with its defining characteristic in List II.
List I: (Approach)
P. Visual Scoring
Q. Destructive Sampling
R. HTP Non-Destructive
S. Aerial Phenomics
List II: (Characteristic)
1. Continuous time-series evaluation
2. Subjective qualitative assessment
3. High-throughput field scale imaging
4. Yielding absolute biomass but preventing temporal tracking
(A) P-2, Q-4, R-1, S-3
(B) P-1, Q-2, R-3, S-4
(C) P-3, Q-1, R-4, S-2
(D) P-4, Q-3, R-2, S-1

2015

171. Which phenomenon best describes pleiotropy in an agricultural context?
(A) A single gene mutation altering both final grain size and early seedling vigor simultaneously
(B) A severe drought wiping out an entire crop
(C) The interaction between soil nitrogen and ambient temperature
(D) Multiple distinct genes controlling a single trait like plant height

2008

172. Why do hyperspectral sensors generate vastly more data volume than standard RGB sensors?
(A) Hyperspectral sensors capture images at a much slower speed
(B) Hyperspectral sensors record reflectance across hundreds of narrow contiguous spectral bands per pixel
(C) Hyperspectral sensors physically fly closer to the ground
(D) Hyperspectral sensors must physically touch the plant leaves

2014

173. What role does "ground truthing" play in a high-throughput phenotyping pipeline?
(A) It provides manual measurements to validate and calibrate the predictive models derived from indirect sensor data
(B) It is the process of physically removing background soil from digital images
(C) It entirely replaces the need for any aerial drone flights
(D) It actively edits the genetic material in the ground roots

2018

174. Which of the following is considered an emergent macroscopic phenotype?
(A) Total grain yield per hectare
(B) The precise diameter of a single xylem vessel
(C) The localized operating efficiency of a single chloroplast
(D) A specific point mutation in a single gene

2023

175. Identify the INCORRECT statement regarding conventional phenotyping.
(A) It often acts as a massive bottleneck in modern breeding programs
(B) It perfectly scales with the rapid output of Next-Generation Sequencing
(C) It relies heavily on subjective visual scoring and destructive sampling
(D) It struggles to capture high-resolution temporal growth dynamics

2007

176. What is a specific advantage of utilizing a controlled-environment automated greenhouse platform ("plants to sensors")?
(A) It perfectly replicates all complex multi-stress interactions found in natural open fields
(B) It allows for the use of heavy tractors inside the greenhouse
(C) It completely eliminates the need for sensor calibration
(D) It provides highly precise control over environmental variables, isolating strict genotypic responses

2002

177. How is the Normalized Difference Vegetation Index (NDVI) mathematically derived?

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field

(D) Mapping takes one month, but accurately assessing drought tolerance in the field takes multiple years

2013

125. Identify the correct biological sequence outlining the central dogma as it relates to trait expression.

(A) Phenome → Proteome → Transcriptome → Genome

(B) Genome → Transcriptome → Proteome → Phenome

(C) Proteome → Genome → Phenome → Transcriptome

(D) Transcriptome → Phenome → Genome → Proteome

2002

126. Why is high temporal resolution crucial for understanding crop phenology via HTP?

(A) Plant developmental stages are highly dynamic and transient traits might be missed with infrequent sampling

(B) High temporal resolution perfectly substitutes for high spatial resolution

(C) It permanently arrests the plant's growth at a desired stage

(D) It prevents the plant from reacting to environmental stress

2009

127. Which statement highlights a key limitation of visual manual scoring for disease resistance?

(A) It is subjective and lacks the continuous quantitative resolution provided by digital image analysis

(B) It completely fails to identify dead plants

(C) It requires highly expensive multispectral cameras

(D) It cannot be performed on adult plants

2007

128. What describes the "plants to sensors" phenotyping paradigm?

(A) Using drones to monitor massive broad-acre farms

(B) Utilizing automated conveyor belts to transport potted plants to stationary imaging cabinets

(C) Driving a sensor-equipped tractor through an experimental field plot

(D) Using a handheld leaf spectrometer on stationary field plants

2016

129. How does the integration of genomic and phenomic data facilitate Marker-Assisted Selection (MAS)?

(A) By precisely mapping physiological phenes to specific QTLs, breeders can select for desirable alleles earlier and more reliably without waiting for final yield evaluation

(B) It eliminates the need for genetic markers

(C) It fundamentally alters the Mendelian inheritance of traits

(D) It ensures all genes exhibit pleiotropic effects

2023

130. Given below are statements about multispectral imaging:

I. It captures visible light along with specific invisible bands like near-infrared (NIR).

II. It is highly effective for calculating vegetation indices such as NDVI.

III. It typically captures hundreds of contiguous, ultra-narrow bands.

IV. It can be easily mounted on UAVs for field-scale assessments.

Which of the above statement(s) is/are correct?

(A) I, II and IV

(B) II, III and IV

(C) I and III

(D) I, II and III

2011

131. What is the primary role of Ground Control Points (GCPs) in UAV-based field phenotyping?

(A) To provide battery charging stations for the drones

(B) To ensure precise spatial accuracy and geo-referencing when stitching aerial images into an orthomosaic map

(C) To actively emit hyperspectral radiation for the camera to read

(D) To automatically harvest the crop at the end of the season

2017

132. Which biological entity acts as the immediate link between the genotype and the broader functional metabolome?

(A) The transcriptome and proteome

(B) The plastome

(C) The phene

(D) The biome

2014

133. What is the most accurate characterization of a complex crop trait like drought tolerance?

(A) It is governed solely by a single dominant

NODIA

specific latitude
(D) A uniform application of synthetic fertilizer across the entire region

2009

186. How does computer vision transition raw sensor data into a quantifiable biological trait?
(A) By altering the DNA sequence of the plant based on the image
(B) By using algorithms to segment the image, recognize features, and mathematically calculate metrics
(C) By simply storing the images on a hard drive for manual viewing
(D) By destroying the camera after a single use

2025

187. What is the central dogma's primary role in establishing the genome-to-phenome relationship?
(A) It mathematically calculates the exact final yield of the crop
(B) It describes the flow of genetic information from DNA to RNA to functional proteins that dictate basic phenes
(C) It describes the physical architecture of the plant canopy
(D) It strictly limits phenotypic plasticity

2012

188. Which metric provides the most accurate estimation of a crop's total 3D architectural volume?
(A) Standard NDVI calculations
(B) A high-density 3D point cloud generated by terrestrial LiDAR scanning
(C) Maximum quantum efficiency of Photosystem II
(D) Canopy temperature depression

2012

189. What is a "phenomic marker" effectively used for in breeding programs?
(A) Serving as a rapid, high-throughput, sensor-derived proxy trait to indirectly select for complex physiological performance or yield
(B) Acting as a physical tag identifying the field plot number
(C) Altering the physical structure of a specific chromosome
(D) Suppressing the expression of a major disease-resistance gene

2022

190. Determine the correct sequence for developing a machine learning trait extraction model, then select the matching option.
I. Train the predictive machine learning algorithm
II. Acquire raw images and manually annotate ground-truth data
III. Deploy the model to automatically extract traits from new images
IV. Extract mathematical features from the segmented training images
(A) II - IV - I - III
(B) I - II - III - IV
(C) IV - II - I - III
(D) II - I - IV - III

2005

191. Which scenario best represents the "phenotyping bottleneck"?
(A) An automated greenhouse generates more data than can be analyzed
(B) A breeding program sequences 10,000 lines in a week but takes 5 years to manually measure their drought tolerance
(C) A drone runs out of battery before scanning the entire field
(D) Plants fail to express their genetic potential due to severe heat

2017

192. What makes the concept of a phene critical for dissecting complex traits?
(A) It breaks down highly complex traits into their elemental, physiological, or structural building blocks
(B) It perfectly isolates the genotype from the environment
(C) It forces researchers to rely entirely on qualitative visual scoring
(D) It relies heavily on destructive sampling methods

2011

193. Identify the correct relationship between spatial resolution and phenotyping accuracy.
(A) Lower spatial resolution always increases accuracy by averaging out noise
(B) Higher spatial resolution captures finer anatomical details, enabling the precise segmentation of specific plant organs
(C) Spatial resolution has no mathematical bearing on image analysis
(D) High spatial resolution completely eliminates temporal resolution

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(C) By mathematically erasing the effects of pleiotropy
(D) By strictly limiting the study to single-gene Mendelian traits

2013

230. Given below are statements about integrating phenomics and genomics:

I. It improves the predictive accuracy of Genomic Selection (GS) models.
II. It utilizes phenomic markers as proxy traits for complex physiological processes.
III. It completely removes the influence of micro-environmental variations.
IV. It facilitates more efficient Marker-Assisted Selection (MAS) by mapping dynamic trait trajectories over time.
V. It eliminates the necessity for large-scale multi-environment field trials.

Which of the above statement(s) is/are INCORRECT?
(A) I, II and IV
(B) III and V
(C) II, IV and V
(D) I, III and V

****

NODIA

2015

203. Identify the principal reason why accurate phenotyping of mapping populations improves Genomic Selection (GS) models.
(A) Accurate phenotyping permanently edits the elite cultivars' DNA
(B) It improves the precision of the model training set, enhancing the ability to predict breeding values
(C) It ensures the model ignores all environmental variance
(D) It eliminates the need for computational power

2006

204. What does the term "pleiotropy" denote in genetic and phenomic studies?
(A) Multiple environmental factors affecting one trait
(B) A single gene simultaneously influencing the expression of multiple, potentially unrelated, phenotypic traits
(C) The synergistic interaction between two completely different plant species
(D) The exact physical mapping of a gene on a chromosome

2016

205. Which technological approach is most suited for extracting fine-scale geometric traits, like the precise angle of a single leaf, non-destructively in the field?
(A) High-resolution terrestrial LiDAR scanning and 3D modeling
(B) Broad-acre satellite imagery
(C) Destructive chemical assays
(D) Low-resolution thermal thermography

2024

206. How does the integration of genomic and phenomic data overcome the limitations of classic quantitative genetics?
(A) By ignoring the environment entirely
(B) By linking genetic markers with continuous, high-resolution biological trait kinetics
(C) By enforcing destructive sampling on all mapping populations
(D) By strictly limiting analysis to qualitative Mendelian traits

2012

207. What is a known consequence of phenotyping inaccuracy in a GWAS analysis?
(A) Perfect alignment of major QTLs
(B) The complete erasure of the plant's genomic data
(C) The elimination of pleiotropic gene effects
(D) A drastic increase in false positives and false negatives

2003

208. Which component is the fundamental biological bridge translating genomic instructions into initial functional reality?
(A) The transcriptome (mRNA)
(B) The mature macroscopic phenotype
(C) The localized environmental covariate
(D) The artificial intelligence algorithm

2024

209. What defines the specific limitation of a "plants to sensors" greenhouse platform?
(A) Controlled greenhouse conditions often fail to replicate the complex GxE dynamics of real-world agricultural fields
(B) It requires the destruction of the plants to transport them
(C) It cannot utilize standard RGB or thermal cameras
(D) It provides excessively high temporal resolution

2021

210. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A): High-throughput phenotyping fundamentally resolves the phenotyping bottleneck.
Reason (R): It replaces slow, subjective, destructive manual measurements with rapid, objective, automated, and continuous sensor-based data capture.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

NODIA

2007

211. What is the advantage of using haplotype blocks instead of individual SNPs in genomic-phenomic association studies?
(A) It decreases the overall amount of genomic data processed
(B) It increases the capture of genetic variation by considering the inheritance of linked alleles
(C) It eliminates the need for any phenotypic data

(D) It makes complex traits behave as single Mendelian units

2014

212. Identify the fundamental purpose of utilizing "ground truthing" data.
(A) To strictly rely on uncalibrated mathematical algorithms
(B) To ensure that drones do not crash into the soil
(C) To provide accurate measurements used to calibrate and validate indirect sensor-based machine learning models
(D) To physically dig into the ground to map root systems destructively

2013

213. Which challenge is most associated with the 'Big Data' aspect of high-throughput phenomics?
(A) The lack of available sensors
(B) The high cost of seed packets
(C) Storing, transferring, and processing terabytes of multi-dimensional image data
(D) The inability to find suitable field locations

2018

214. Which metric, derived directly from multispectral data, relies on the differential reflection of visible red and near-infrared wavelengths?
(A) $\frac{F_v}{F_m}$
(B) Leaf Area Index (LAI)
(C) Normalized Difference Vegetation Index (NDVI)
(D) Vapor Pressure Deficit (VPD)

2010

215. What makes aerial UAV platforms particularly advantageous for agricultural phenomics?
(A) They scan massive field trials rapidly and non-destructively without causing soil compaction
(B) They carry much heavier payloads than ground-based tractors
(C) They perfectly capture high-resolution deep root architecture
(D) They fundamentally alter the micro-environment of the crop

2006

216. What characterizes 'deep phenotyping' in the context of modern plant science?
(A) Measuring a single trait at the end of the season
(B) The intensive, multi-level characterization of an organism's traits using diverse HTP technologies
(C) Planting seeds at a greater depth in the soil to measure drought
(D) Using only visual scores to evaluate root systems

2003

217. How does high spatial resolution enhance the accuracy of thermal infrared phenotyping in the field?
(A) It strictly relies on satellite imagery
(B) It ensures that only pure canopy pixels are measured, excluding confounding background soil pixels
(C) It averages the entire field into a single temperature value
(D) It directly measures the water potential within the root xylem

2025

218. What is the primary benefit of 'edge computing' on a UAV phenotyping platform?
(A) It makes the drone fly higher
(B) It allows for real-time data processing and trait extraction during the flight, reducing post-processing time
(C) It replaces the need for a camera
(D) It increases the physical weight of the payload

2025

219. Which biological principle dictates that a single genotype can express different phenotypic trait values across varying environments?
(A) Mendelian segregation
(B) Phenotypic plasticity
(C) Complete epistasis
(D) Genetic linkage

2015

220. Match the modeling or genetic concept in List I with its description in List II.
List I: (Concepts)
P. Reaction Norm
Q. Pleiotropy
R. Phene Synergism
S. Genomic Selection
List II: (Descriptions)
1. The non-additive emergent effect of multiple elementary phenes
2. A single gene influencing multiple different biological traits
3. Using genome-wide markers and phenomic data to predict complex traits
4. The graphical function linking phenotype

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expression to an environmental gradient
(A) P-4, Q-2, R-1, S-3
(B) P-1, Q-3, R-2, S-4
(C) P-2, Q-1, R-4, S-3
(D) P-3, Q-4, R-1, S-2

2023

221. What defines an environmental covariate in the mathematical modeling of high-throughput field phenomics?
(A) The exact physical location of a specific QTL
(B) A recorded variable used to statistically account for non-genetic variance during trait modeling
(C) A specific type of computer vision algorithm
(D) The subjective score given by a human evaluator

2006

222. Which imaging technique is most uniquely capable of detecting subtle, pre-symptomatic shifts in a leaf's internal pigment composition before human eyes can perceive chlorosis?
(A) Hyperspectral imaging
(B) Standard RGB photography
(C) Low-resolution thermal imaging
(D) Visual manual scoring

2019

223. What is the fundamental functional role of a phene in an organism's biology?
(A) It is simply a synonym for the entire genome
(B) It acts as the elemental building block of function that combines to form complex emergent traits
(C) It acts as an environmental stressor strictly external to the plant
(D) It is an entirely theoretical metric unmeasurable by modern sensors

2006

224. How do ground-based mobile field gantries provide an advantage over traditional tractor-based phenomobiles?
(A) They offer near-perfect sub-millimeter spatial repeatability across temporal scans
(B) They are fundamentally cheaper and easier to build
(C) They fly rapidly over the field without touching the ground
(D) They exclusively rely on destructive sampling

2025

225. Which parameter is critical to measure using chlorophyll fluorescence to detect early pathogen stress?
(A) Total root volume
(B) Maximum quantum efficiency of Photosystem II ($\frac{F_v}{F_m}$)
(C) Whole canopy temperature depression
(D) Physical plant height via LiDAR

2006

226. What fundamentally limits the transition of "plants to sensors" greenhouse discoveries into elite commercial field cultivars?
(A) Controlled greenhouse environments fail to replicate the complex multi-stress interactions found in natural fields
(B) Greenhouse plants fundamentally lack DNA
(C) Commercial fields cannot support automated tractors
(D) Drones cannot fly over commercial fields

2016

227. Identify the primary advantage of employing Convolutional Neural Networks (CNNs) in plant phenomics.
(A) They randomly alter the genetic composition of the seed
(B) They excel at automatically learning and extracting complex spatial features directly from unstructured image data
(C) They eliminate the necessity for computer processing power
(D) They fundamentally rely on strictly destructive manual measurements

2003

228. Which component acts as the foundational variable dictating the baseline potential of an organism's entire phenome?
(A) The localized micro-environment
(B) The temporal resolution of the scanning sensor
(C) The specific genotype
(D) The spatial resolution of the UAV imagery

2017

229. How does precise phenotyping via HTP directly impact Genome-Wide Association Studies (GWAS)?
(A) By completely replacing the need to sequence the plant's genome
(B) By lowering phenotypic error variance, thereby increasing the signal-to-noise ratio needed to detect associations

NODIA

26. (B) Variance resulting from the interaction between genotype and environment
In quantitative genetics, the total phenotypic variance is decomposed into several components. The term representing the interaction between the genotype and the environment accounts for the reality that different genotypes may respond uniquely to varying environmental conditions. This interaction means the performance rank of varieties can change across locations, which is a critical consideration for breeders developing widely adapted crops.

27. (D) Genotypic variance (V_g)
When environmental conditions are perfectly uniform and there are no interactions between genetics and the environment, all observed differences between individuals must stem from their genetic makeup. In this theoretical scenario, the environmental variance and interaction variance are zero. Consequently, the total phenotypic variance is entirely dictated by the genotypic variance, reflecting the inherited differences within the population being studied.

28. (A) Cultivar A outyields Cultivar B under drought, but Cultivar B outyields Cultivar A under irrigation
Genotype by environment interaction is clearly illustrated when the relative performance of cultivars switches across different conditions. In this case, Cultivar A excels under stress, while Cultivar B is superior under optimal irrigation. This crossover effect demonstrates that neither genotype is universally superior, as their phenotypic expression is specifically modulated by the external environment, complicating the selection of general-purpose varieties.

29. (B) It complicates the selection of broadly adapted varieties
Significant interactions between genotypes and environments mean that a variety performing well in one location may fail in another. This inconsistency makes it difficult for breeders to identify crops with stable, high performance across diverse geographical regions. Consequently, breeding programs must conduct extensive multi-environment trials to characterize these interactions and ensure that selected varieties meet the needs of specific target environments.

30. (B) I and III
Phenotypic plasticity is the capacity of a single genotype to produce different phenotypes when exposed to varying environments. This is a fundamental adaptive mechanism that can be graphically visualized using reaction norms, which plot the trait values against an environmental gradient. Plasticity is not always detrimental; it often enhances survival and fitness by allowing plants to adjust to changing conditions.

31. (A) Reaction norm
A reaction norm is a mathematical or graphical representation of the range of phenotypes produced by a single genotype across different environmental conditions. By plotting these responses, researchers can visualize how sensitive a specific genotype is to environmental changes. This concept is central to studying phenotypic plasticity and understanding how genes and environment interact to determine the final observable traits of plants.

32. (A) Dynamic physiological adjustments, such as stomatal closure, that maintain plant survival.
High phenotypic plasticity allows plants to make critical adjustments in response to environmental stress, enhancing their survival. For example, the ability to rapidly close stomata during a sudden drought prevents excessive water loss. These flexible responses enable genotypes to cope with unpredictable conditions, providing a significant advantage in variable agricultural landscapes where plants must adapt to fluctuating resources and weather patterns.

33. (D) Micro-environmental variations - Broad, regional climate shifts across continents
Micro-environmental variations refer to small-scale differences within a specific field or plot, such as localized soil moisture or light gradients. In contrast, broad regional shifts are considered macro-environmental factors. Understanding these small-scale variations is crucial in phenotyping because they introduce noise that can mask genetic differences, requiring precise spatial monitoring and statistical correction during high-throughput data analysis.

34. (A) They introduce spatial noise requiring statistical correction for accurate assessment.
Micro-environmental variations, such as localized differences in soil fertility or water availability, create spatial noise in phenotyping data. Even

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ANSWERS

1. (A) Phenome
The phenome encompasses the total set of observable characteristics or traits of an organism, which result from the interaction between its genetic makeup and the surrounding environment throughout its life cycle. It represents the ultimate manifestation of the genome across various biological scales, including molecular, physiological, and morphological attributes, reflecting dynamic responses to external conditions and developmental stages.

2. (C) The phenotype includes environmental interactions
While the genotype represents the fixed genetic blueprint of an organism, the phenotype is the observable expression of those genes. A critical distinction lies in the role of the environment, which actively shapes phenotypic traits. Phenotypes result from the intricate interplay between genetic instructions and external factors, leading to variations that are not exclusively determined by inherited DNA sequences.

3. (A) A phene
In the hierarchy of phenomics, a phene is recognized as the most basic, irreducible unit of a phenotype. This concept is analogous to a gene in genetics, representing a fundamental trait component that can be analyzed independently. Understanding phenes allows researchers to deconstruct complex agricultural characteristics into simpler physiological or anatomical modules for more precise genetic mapping and biological modeling.

4. (D) The genome predetermines the final phenome regardless of any external environmental influences.
The relationship between the genome and phenome is not strictly deterministic. While the genome provides the underlying potential, the final phenome is highly dynamic and context-dependent, heavily influenced by environmental inputs and epigenetic modifications. Asserting that the genome alone determines the phenome ignores the fundamental biological reality of phenotypic plasticity and the impact of external stress factors on growth.

NODIA

5. (B) Genotype refers to genetic makeup, while phenotype is the expressed observable trait
Genotype and phenotype represent two distinct biological concepts. The genotype is the internal genetic code inherited by an organism, providing the instructions for development and function. In contrast, the phenotype is the actual physical manifestation of those instructions, including visible morphological features and biochemical properties, which are measurable and subject to change based on specific environmental conditions and management.

6. (C) High-throughput non-destructive phenotyping across environments
Capturing a complete phenome requires evaluating traits throughout the entire growth cycle and under diverse conditions. High-throughput non-destructive methods enable continuous data collection without killing the plants, providing a comprehensive view of developmental dynamics. This approach accounts for spatial and temporal variations, offering a more representative analysis of crop performance than single-point observations or traditional, labor-intensive destructive sampling methods.

7. (D) Transcription and translation
The flow of biological information from the genome to the phenome is governed by the central dogma. Transcription converts DNA into messenger RNA, which then serves as a template for translation into specific proteins. These proteins function as structural components or enzymes, driving the metabolic processes and physiological pathways that ultimately manifest as the observable traits and functions of the organism.

8. (A) They introduce complexity, causing a single gene to potentially produce multiple phenes
Post-translational modifications significantly diversify the proteome, allowing a single gene to generate various functional protein forms. This biochemical complexity means that one genetic sequence can influence multiple distinct physiological or structural traits, known as phenes. Such modifications illustrate why the

2009

194. Why is continuous, high temporal resolution monitoring crucial for studying phenological transitions?
(A) Transitions are highly dynamic; infrequent sampling will likely miss the exact timing
(B) It completely prevents the plant from reaching maturity
(C) It artificially forces the plant to transition faster
(D) It inherently destroys the tissue being monitored

2004

195. Which statement accurately defines "phene synergism"?
(A) The interaction of elemental phenes producing an emergent complex phenotype not predictable by simple additive effects
(B) The mutual destruction of two alleles at the same locus
(C) The ability of a drone to carry multiple sensors simultaneously
(D) The direct, independent effect of a single gene on yield

2004

196. How does Multispectral imaging specifically calculate the NDVI index?
(A) It strictly uses the blue and green visible bands
(B) It relies on the distinct differential reflectance of red light and near-infrared light
(C) It maps the 3D volume using laser pulses
(D) It utilizes the thermal emission of the plant canopy

2015

197. What is the fundamental premise of Genome-Wide Association Studies (GWAS)?
(A) They ignore phenotypic data entirely to focus strictly on gene sequences
(B) They aim to statistically link specific genetic variants (SNPs) across the entire genome with precisely measured phenotypic traits
(C) They utilize strictly destructive sampling techniques to identify proteins
(D) They aim to completely eliminate phenotypic plasticity

2008

198. Which environmental covariate is most critical to continuously measure when analyzing thermal imaging data for drought stress?
(A) Ambient air temperature and Vapor Pressure Deficit (VPD)
(B) Deep soil nitrogen content
(C) The magnetic field orientation of the field
(D) The precise genetic pedigree of the plant

2024

199. What distinguishes true phenotypic plasticity from genetic mutation?
(A) Plasticity is the variable expression of the same genotype; mutation is an actual structural change to the DNA
(B) Plasticity involves a permanent change in the DNA sequence; mutation is temporary
(C) They are mathematically identical phenomena
(D) Plasticity only occurs in completely sterile environments

2002

200. Given below are statements about HTP platform paradigms:
I. "Plants to sensors" usually implies a controlled greenhouse setting with conveyors.
II. "Sensors to plants" involves mobile platforms operating directly in field conditions.
III. Both paradigms entirely eliminate the concept of GxE interactions.
IV. UAVs are primarily associated with the "sensors to plants" paradigm.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) I, II and III
(C) II, III and IV
(D) I and IV

2025

201. What acts as the ultimate determining boundary for a plant's entire possible phenotypic expression (its reaction norm)?
(A) The localized micro-environment
(B) The specific spatial resolution of the camera used
(C) Its underlying genotype
(D) The specific fertilizer regime applied

2016

202. Which specific deep learning architecture is uniquely optimized for processing grid-like topological data, such as high-resolution digital images?
(A) Recurrent Neural Networks (RNN)
(B) Support Vector Regression (SVR)
(C) Principal Component Analysis (PCA)
(D) Convolutional Neural Networks (CNN)

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resilience is an emergent, complex trait that depends on many interacting factors, including root depth, water-use efficiency, and stomatal control. This example highlights how elementary biological components combine to form the broad physiological outcomes observed in agricultural crops and plants.

18. (C) Reduced mapping resolution due to compounding multiple distinct genetic controls.
Treating a complex trait as an irreducible phene complicates genetic mapping because the trait is influenced by numerous genes across multiple pathways. This aggregation introduces statistical noise and dilutes the signal from individual genetic loci. Consequently, mapping resolution is significantly reduced, making it difficult to identify the specific causal genes responsible for the underlying physiological components that contribute to the trait.

19. (A) Xylem vessel diameter
Xylem vessel diameter is a specific, irreducible anatomical measurement that serves as a fundamental building block for water transport. Unlike total biomass or final yield, which are composite outcomes of numerous growth processes and environmental interactions, vessel diameter is an elementary feature. Therefore, it fits the definition of a phene, representing a basic unit within the structural hierarchy of the plant.

20. (B) P-2, Q-1, R-4, S-3
Biological classification separates the genetic code from its physical expression. The genotype represents genetic composition, while the phenome is the aggregate of all expressed phenotypes. A phene serves as the basic, irreducible unit of an observable trait. Conversely, complex traits are macroscopic outcomes resulting from multiple interacting biological processes, reflecting the hierarchical organization of traits from molecular to organismal levels.

21. (B) The interaction of distinct phenes producing a non-additive emergent trait.
Phene synergism occurs when different elementary traits interact to produce a macroscopic outcome that is greater than or different from the simple sum of its parts. These interactions often lead to emergent properties, where the combined effect of several physiological mechanisms, such as root architecture and nutrient uptake, results in a complex trait like improved crop yield or stress tolerance.

22. (C) Pleiotropy
Pleiotropy is a genetic phenomenon where a single gene or locus influences multiple, often unrelated, phenotypic traits or phenes. This occurs because the gene product may function in several different biological pathways or be expressed in various tissues. Understanding pleiotropy is vital in breeding, as selecting for one desirable trait might inadvertently alter other characteristics due to shared genetic control.

23. (B) The gene alters both water uptake efficiency and nutrient acquisition simultaneously
When a gene regulating root architecture exhibits pleiotropy, its effects extend beyond a single function. By altering the physical structure of the roots, the gene simultaneously impacts multiple processes, such as the efficiency of water absorption and the acquisition of soil nutrients. This demonstrates how a single genetic change can produce broad, integrated effects on the plant's overall physiological performance.

24. (C) They result from the complex synergistic interaction of numerous elementary phenes.
Macroscopic phenotypes, such as crop yield or total biomass, are not determined by single genes or isolated traits. Instead, they are emergent properties that arise from the synergistic interaction of many underlying, elementary phenes. These interactions integrate various physiological, morphological, and biochemical processes, reflecting the complex organizational hierarchy that bridges the gap between the genotype and the final organismal form.

NODIA

25. (B) The total harvestable grain yield of a wheat field
Grain yield is a classic example of an emergent macroscopic phenotype because it is the final outcome of countless underlying processes. It integrates photosynthesis, nutrient uptake, flowering time, and environmental interactions throughout the season. Unlike simple traits like trichome density or internode length, yield cannot be reduced to a single biological unit, as it represents the cumulative performance of the crop.

relationship between the genome and phenome is not a simple linear progression but a complex, multi-layered regulatory network.

9. (B) mRNA synthesis
In the molecular pathway from genetic code to physical expression, transcription is the first step where a specific DNA segment is copied into RNA. Specifically, messenger RNA synthesis represents the immediate output of this process. These transcripts carry vital genetic instructions to the ribosomes, where they are eventually translated into the proteins that build and maintain an organism's phenotypic traits.

10. (D) A is false but R is true.
The central dogma explains the basic flow of genetic information but is insufficient for predicting the entire phenome. Final phenotypic expression is shaped by a multitude of factors, including epigenetic silencing, environmental stress, and post-translational protein alterations. Therefore, knowing the genome sequence alone does not account for the dynamic and context-sensitive nature of an organism's actual physical and biochemical traits.

11. (A) Transcriptome, proteome, and metabolome
The bridge between the static genome and the complex phenome consists of several intermediate molecular layers. The transcriptome reflects active gene expression, while the proteome comprises the resulting proteins. The metabolome represents the chemical end products of cellular processes. Together, these functional layers provide a comprehensive understanding of how genetic information is translated into specific biological functions and observable characteristics.

12. (C) It demonstrates that multiple interacting gene products form complex metabolic networks generating traits
Biological pathways reveal that traits are rarely the result of isolated gene actions. Instead, they emerge from complex networks of interacting gene products, such as enzymes and signaling molecules. These pathways integrate various internal and external signals to coordinate metabolic and developmental processes. Understanding these networks explains how genotypes generate phenotypes through intricate, interdependent systems rather than simple associations.

13. (D) The basic, indivisible building block of a complex trait
In modern phenomics, a phene is defined as an elementary and irreducible unit of a phenotype. It represents the most fundamental measurable component of a trait, such as a specific anatomical feature or physiological process. By identifying these building blocks, scientists can better understand the composition of complex macroscopic traits, facilitating more precise genetic analysis and crop improvement strategies.

14. (C) Phenome - The static, unchangeable physical traits of an organism
The phenome is incorrectly described as static or unchangeable. In reality, it is a highly dynamic entity that evolves throughout an organism's life cycle in response to environmental fluctuations and developmental cues. While the genome remains relatively constant, the phenome reflects the ongoing interaction between genetics and the environment, making it a transient and context-dependent representation of an organism's state.

15. (B) Counting the total number of chromosomes in a karyotype
The concept of a phene focuses on deconstructing observable traits into fundamental physiological or morphological units. It is highly relevant for modeling complex mechanisms like drought tolerance or architectural features. However, counting chromosomes is a genomic or cytogenetic task that deals with the physical structure of the genetic material itself, rather than the functional or expressed phenotypic units of the organism.

16. (D) A trait is an aggregate of multiple interacting phenes
A clear distinction exists between simple phenes and complex traits. A phene is an elementary, irreducible unit of observation. In contrast, a complex trait, such as yield or overall vigor, is an aggregate outcome produced by the synergistic interaction of many underlying phenes. Recognizing this hierarchy is essential for accurately mapping the genetic basis of multifaceted agricultural and biological characteristics.

17. (A) Stomatal density is a phene, while overall drought resilience is a complex trait
Stomatal density represents a fundamental, measurable anatomical unit, making it a classic example of a phene. In contrast, drought

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in a seemingly uniform field, these small-scale fluctuations cause plants with the same genotype to express different phenotypes. To accurately assess genetic potential, researchers must use statistical models and spatial corrections to account for this environmental noise and isolate true genetic effects.

35. (D) To isolate the true genetic effect by accounting for environmental variance (V_e)
Monitoring environmental covariates like temperature, light, and soil moisture is essential for accurate phenotyping. Since phenotypes are influenced by both genes and the environment, recording these factors allows researchers to mathematically account for environmental variance. By adjusting for these external influences, scientists can more effectively isolate the true genetic contribution to a trait, improving the precision of breeding selections.

36. (B) Small temperature gradients caused by the positioning of cooling fans
Micro-environmental variations involve small-scale differences in the immediate surroundings of a plant. In a greenhouse, the positioning of equipment like cooling fans or heaters can create localized temperature gradients. These subtle differences mean that plants in different areas of the same greenhouse experience slightly different conditions, which can influence their phenotypic expression and introduce experimental error if not properly managed.

37. (B) The gap between high-speed, low-cost genomic sequencing and slow, labor-intensive trait evaluation
The phenotyping bottleneck describes the significant disparity between our ability to rapidly sequence genomes and our ability to accurately measure phenotypes. While genomic technologies have advanced exponentially, traditional phenotyping remains slow, manual, and expensive. This imbalance hinders agricultural progress, as researchers lack the high-resolution trait data needed to fully understand and utilize the vast amount of available genomic information.

38. (A) The widespread adoption of Next-Generation Sequencing (NGS)
The phenotyping bottleneck became a major challenge following the advent of Next-Generation Sequencing. NGS allowed researchers to sequence thousands of genomes quickly and affordably, generating massive amounts of genetic data. However, the methods for evaluating physical traits did not keep pace, creating a situation where genetic information far exceeds the phenotypic data required to link specific genes to plant performance.

39. (C) They often require destructive sampling, preventing temporal time-series analysis on the same plant
A major drawback of traditional phenotyping is its reliance on destructive sampling, such as harvesting plants to measure biomass. Because the plant is destroyed, it is impossible to track its individual growth trajectory over time. This prevents the collection of continuous time-series data, which is essential for understanding the dynamic physiological responses of crops to environmental changes throughout the season.

40. (B) Visual manual scoring → Destructive sampling → High-throughput non-destructive phenotyping
Plant evaluation has evolved from subjective visual scoring by breeders to more objective but destructive physical measurements. Recently, the field has transitioned toward high-throughput non-destructive phenotyping, which uses advanced sensors and automation. This latest stage allows for the rapid, precise, and continuous monitoring of traits without harming the plants, overcoming the limitations of previous manual and terminal evaluation methods.

41. (A) It restricts breeders to evaluating only thousands of lines instead of millions, reducing selection intensity
Traditional phenotyping is labor-intensive and slow, which severely limits the number of plants or lines that can be evaluated. In modern breeding, this scale limitation means that researchers can only process a small fraction of the available genetic diversity. This reduction in population size decreases selection intensity, ultimately slowing down the rate of genetic gain and crop improvement.

42. (A) Decreased resolution, leading to broader QTL intervals and missing minor loci.
Inaccurate phenotyping negatively impacts the precision of genetic mapping. High levels of measurement error increase the noise in the data, which reduces the statistical power to

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107. (C) A localized drop in Photosystem II operating efficiency ($\frac{F_v}{F_m}$) at the infection site
Early detection of pathogens is possible because infections often disrupt the photosynthetic machinery before physical lesions appear. Chlorophyll fluorescence imaging can detect a localized drop in the operating efficiency of Photosystem II at the site where the pathogen is active. This pre-symptomatic physiological change serves as a sensitive indicator of disease, providing an opportunity for early intervention and research into plant-pathogen interactions.

108. (B) Genetically dissecting a complex trait into smaller components until a fundamental unit is isolated
Defining a phene involves a reductionist approach where a complex trait is deconstructed into its simplest, irreducible parts. By genetically dissecting these traits, researchers can identify the individual physiological or anatomical building blocks that are controlled by specific genomic regions. This method allows for a more detailed understanding of the genetic basis of traits, facilitating the identification of fundamental units for biological modeling.

109. (D) Conventional phenotyping is manual and severely limited in daily throughput
The primary limitation of conventional phenotyping is its reliance on manual labor, which is slow and cannot scale to the requirements of modern genomics. While sequencing has become incredibly fast and automated, evaluating traits in the field often still involves people manually measuring plants. This disparity in throughput creates a bottleneck, as researchers cannot phenotype large populations quickly enough to keep pace with genomic data generation.

110. (D) A is false but R is true.
Automated phenotyping platforms improve objectivity and speed but do not completely eliminate phenotypic error. Experimental variance is still introduced by micro-environmental fluctuations, sensor noise, and calibration issues. While high-throughput systems provide high-quality data, some level of error always remains, requiring careful experimental design and statistical analysis to accurately account for the non-genetic factors that influence the observed traits of the plants.

111. (B) Genomic Selection (GS)
Genomic Selection is a modern breeding strategy that uses genome-wide SNP markers to predict the breeding values of individuals. This process relies on a training population where both genomic and high-throughput phenomic data are available. By integrating these two types of information, GS can more accurately predict performance for complex, polygenic traits, allowing breeders to select superior lines earlier and more efficiently.

112. (A) It records continuous reflectance across hundreds of narrow bands, capturing specific pigment features
Hyperspectral imaging is superior for biochemical analysis because it captures detailed reflectance data across hundreds of narrow, contiguous bands. This high spectral resolution allows for the detection of specific pigment features and other chemical signatures that are not visible to RGB cameras. By providing a much more granular view of the plant's reflectance spectrum, hyperspectral sensors can identify subtle physiological changes.

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113. (D) The identification of novel, minor-effect alleles due to reduced background noise
Using highly accurate phenotypic data in GWAS significantly improves the ability to detect genetic associations. By reducing the noise caused by measurement error, the statistical power to identify alleles with smaller effects is increased. This leads to the discovery of novel genomic regions that were previously hidden by background variation, providing a more complete picture of the genetic architecture of complex traits.

114. (C) Phene synergism
Phene synergism refers to the phenomenon where independent elementary traits interact to produce an emergent outcome that is more than just the sum of its parts. These non-additive interactions are common in complex traits like yield, where multiple physiological mechanisms work together in a coordinated way. Understanding these synergies is essential for modeling how individual biological components contribute to the overall performance and fitness of a crop.

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can capture phenotypic expression in authentic agronomic environments, accounting for real-world interactions between the genotype and the local climate.

51. (A) Gantries operate on fixed rails over a specific plot, providing extremely precise spatial repeatability
A mobile field gantry is a structure that moves on fixed rails over a dedicated experimental plot. This setup provides superior spatial repeatability compared to tractors, as it can return to the exact same millimeter coordinate for every measurement. This precision is ideal for capturing detailed time-series data and mapping the growth of individual plants with minimal spatial error or soil disturbance.

52. (B) A high-clearance tractor retrofitted with multi-sensor arrays (phenomobile)
A phenomobile is a specialized ground-based vehicle, often a modified high-clearance tractor, equipped with various sensors for crop evaluation. It is designed to drive through field plots, capturing data on canopy structure, temperature, and spectral reflectance. These vehicles allow for high-throughput field phenotyping, enabling breeders to assess large populations under natural conditions while maintaining the flexibility to cover different locations.

53. (A) UAVs provide rapid, high-throughput canopy scanning of vast field areas without causing soil compaction
Unmanned Aerial Vehicles offer a significant advantage in field phenomics due to their speed and lack of physical contact with the ground. UAVs can quickly scan large agricultural areas from above, capturing canopy data without damaging the soil or the plants. This efficiency makes them ideal for monitoring whole-field variability and conducting rapid assessments of large-scale breeding trials or commercial crops.

54. (D) High-resolution RGB digital camera
High-resolution RGB cameras are the most common sensors used on UAVs for assessing crop morphology. These cameras capture visible light, providing images that allow researchers to measure traits like canopy cover, plant height, and architectural features. RGB imaging is foundational for monitoring growth and development, offering a cost-effective way to collect detailed structural information across large field areas from an aerial perspective.

55. (A) Leaf area index, plant height, and architectural geometry
RGB imaging is primarily used to extract structural and morphological traits of plants. By analyzing the visible light captured in these images, researchers can calculate metrics such as leaf area index, canopy height, and the overall geometry of the plant architecture. These traits are essential for monitoring growth rates, assessing biomass, and understanding how different genotypes organize their structural components in the field.

56. (B) Visible to shortwave infrared (VIS-SWIR) spectrum
Multispectral and hyperspectral imaging target the visible to shortwave infrared spectrum to assess the biochemical properties of crops. Different wavelengths within this range are absorbed or reflected based on the presence of specific pigments, water, and organic compounds. By analyzing these spectral signatures, researchers can non-destructively estimate plant health, nitrogen content, and other vital chemical components that reflect physiological status.

57. (D) Multispectral captures a few broad, discrete bands; hyperspectral captures hundreds of narrow, contiguous spectral bands
The primary difference between multispectral and hyperspectral imaging lies in their spectral resolution. Multispectral sensors capture data in a few broad, separate wavelength bands. In contrast, hyperspectral sensors record information across hundreds of narrow, contiguous bands. This higher level of detail allows hyperspectral imaging to detect subtle biochemical changes and specific spectral signatures that are often missed by broader multispectral measurements.

58. (A) By detecting subtle changes in pigment composition and cellular structure via specific reflectance signatures.
Hyperspectral cameras can detect early crop stress because they capture detailed reflectance data across many narrow wavelengths. Stress often causes subtle changes in plant pigments or internal cellular structure before visible symptoms appear. By identifying these specific spectral signatures, researchers can recognize physiological shifts at a pre-symptomatic stage,

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91. (A) Precise phenotyping reduces experimental error (V_e), thereby increasing the calculated broad-sense heritability (H^2)
Heritability is a measure of how much phenotypic variation is due to genetics versus environmental noise. Precise phenotyping improves measurement accuracy, which reduces the experimental error component of the total variance. By decreasing this environmental noise, the proportion of variance attributed to genetics increases, leading to higher calculated heritability and making it easier for breeders to identify and select superior genotypes.

92. (A) The combined, interactive effects of photosynthetic rate, root nitrogen uptake, and sink capacity culminating in final yield
Grain yield is a prime example of phene synergism, as it is produced by the interaction of several physiological processes. Factors like the rate of photosynthesis, the efficiency of nitrogen uptake by the roots, and the capacity of the seeds to store nutrients all work together. The final yield is not just a simple sum of these parts but an emergent result of their combined, synergistic action.

93. (B) By comparing the algorithm's output against a subset of highly accurate, manually measured "ground truth" data
Machine learning models must be validated to ensure their accuracy in trait extraction. Researchers achieve this by comparing the model's automated results against a "ground truth" dataset consisting of manual measurements. This process allows scientists to calculate the error and refine the algorithms, ensuring that the high-throughput sensor data reliably reflects the actual physical and physiological characteristics of the plants.

94. (B) We have millions of sequenced genomes, but lack the corresponding high-resolution trait data to understand their function
The phenotyping bottleneck is a critical issue in the genomic era because our capacity to sequence DNA far exceeds our ability to characterize traits. While we have vast amounts of genetic information, we lack the detailed phenotypic data needed to link these sequences to actual plant performance. Overcoming this gap is essential for translating genomic discoveries into practical agricultural improvements and deeper biological understanding.

95. (B) "Sensors to plants" - Tractors (phenomobiles) driving over field plots
The "sensors to plants" paradigm involves moving measurement tools to stationary plants, typically in a field environment. A common example is the use of phenomobiles, which are tractors equipped with sensor arrays that drive over experimental plots to collect data. This approach allows for the high-throughput evaluation of crops in their natural growing conditions, capturing authentic phenotypic responses to the environment.

96. (B) Normalized Difference Vegetation Index (NDVI)
The Normalized Difference Vegetation Index is based on the specific reflectance properties of vegetation. Green plants absorb most of the red light for photosynthesis but reflect a large portion of near-infrared light. By calculating the ratio between these two bands, NDVI provides a reliable estimate of plant health and green biomass, making it a staple metric in remote sensing and agricultural monitoring.

97. (B) A single gene simultaneously influencing multiple, distinct phenes
Pleiotropy occurs when one gene affects several different phenotypic traits. This is a key factor in the relationship between the genome and phenome, as a single genetic variant can have wide-ranging effects on plant development and physiology. Recognizing pleiotropic effects is crucial in breeding programs to understand how selecting for one trait might lead to unintended changes in other characteristics of the plant.

98. (B) Transpiration rates and leaf temperatures fluctuate rapidly with micro-changes in wind speed and local humidity
Accurate thermal imaging requires an understanding of micro-environmental variations because canopy temperature is highly sensitive to external factors. Small changes in wind speed or local humidity can quickly alter transpiration rates and leaf temperatures. To correctly interpret thermal data as a measure of plant stress, these micro-fluctuations must be monitored and accounted for, ensuring that observed differences reflect true physiological responses.

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67. (A) Plant biomass, canopy volume, and 3D architectural traits
Terrestrial LiDAR is primarily used to estimate structural traits such as canopy volume and 3D architecture. By generating dense point clouds, it allows for the calculation of biomass and the detailed mapping of how plants occupy space. These measurements are essential for understanding growth patterns and structural development, offering a more accurate and non-destructive alternative to traditional manual methods for assessing plant size.

68. (A) Laser pulses partially penetrate canopy gaps to generate a comprehensive 3D point cloud of internal structure.
Unlike 2D RGB imaging, LiDAR can capture the internal structure of dense crop canopies. The laser pulses used in LiDAR can partially penetrate through gaps between leaves, allowing the sensor to record data from multiple layers of the plant. This capability results in a comprehensive 3D point cloud that represents both the outer surface and the internal architectural organization of the crop.

69. (A) It enables the tracking of dynamic growth curves, phenology, and developmental transitions over the growth cycle
High temporal resolution, or frequent measuring over time, is vital for modern crop modeling. It allows researchers to track dynamic growth curves and the exact timing of phenological stages like flowering. By capturing these developmental transitions, scientists can better understand how different genotypes progress through their life cycle and how they respond to environmental changes at specific critical growth stages.

70. (B) P-2, Q-1, R-4, S-3
Different sensor technologies serve specific roles in phenomics. Thermal infrared measures canopy temperature to assess water stress, while LiDAR provides 3D data for architectural and biomass analysis. Chlorophyll fluorescence evaluates photosynthetic efficiency for early stress detection, and hyperspectral imaging captures detailed spectral data to determine biochemical composition. Together, these tools provide a multi-dimensional view of plant health, structure, and physiological function.

71. (A) To separate individual plant organs from background soil and shadow pixels within the captured imagery.
Spatial resolution is crucial for aerial phenotyping because it determines the level of detail in the images. High resolution is necessary to distinguish small plant features, like leaves or stems, from non-plant elements such as soil and shadows. This clarity is essential for accurate image segmentation and feature extraction, ensuring that the resulting data reflects the true phenotypic characteristics of the crop.

72. (C) Image segmentation and feature extraction algorithms
Computer vision pipelines are built on image segmentation and feature extraction. Segmentation involves separating the plant from the background, while feature extraction identifies and quantifies specific traits like size or color. These automated algorithms are foundational to high-throughput phenotyping, as they allow for the rapid and objective processing of large volumes of sensor data into meaningful biological information for breeding and research.

73. (C) It automates the classification and extraction of complex phenotypic traits from large unstructured datasets
Machine learning is essential for handling the massive amounts of data generated by modern phenomics. It allows for the automation of complex tasks, such as identifying specific plant organs or classifying different types of stress symptoms within large image sets. By learning from existing data, these algorithms can extract traits more efficiently and accurately than manual methods, enabling large-scale phenomic analysis.

74. (D) Convolutional Neural Networks (CNN)
Convolutional Neural Networks are the leading deep learning architecture for image-based trait extraction. They are designed to recognize spatial patterns, making them exceptionally effective for tasks like segmenting disease lesions or identifying individual plant structures. CNNs can process raw image data and automatically learn the features needed for accurate classification and measurement, significantly advancing the capabilities of modern high-throughput phenotyping.

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75. (B) Image acquisition → Segmentation (background removal) → Feature extraction → Trait calculation
A standard computer vision pipeline begins with acquiring high-quality images. The next step is segmentation, which removes the background to isolate the plant pixels. Once the plant is isolated, feature extraction identifies relevant characteristics, which are then used for trait calculation. this structured approach ensures that the final phenotypic data is accurately and consistently derived from the raw sensor inputs.

76. (B) By providing highly accurate, multi-environment trait data that improves the training population's predictive accuracy
Advanced phenomics enhances Genomic Selection by improving the quality of the data used to train predictive models. Accurate, high-throughput measurements from multiple environments provide a better understanding of how genotypes express traits under different conditions. This high-resolution phenotypic data increases the predictive power of GS models, allowing breeders to more effectively select for complex traits using genomic information.

77. (B) Managing and aligning massive, multi-dimensional, time-series phenotyping datasets with genotypic data
A major hurdle in modern breeding is the integration of diverse datasets. High-throughput phenomics generates vast amounts of multi-dimensional, time-series data that must be carefully managed and aligned with genomic markers. The complexity of storing, processing, and analyzing these large datasets requires advanced computational infrastructure and sophisticated statistical methods to successfully link genetic variation to the dynamic traits observed in the field.

78. (A) The "genome-to-phenome" predictive modeling approach
The genome-to-phenome modeling approach is the central concept for integrating phenomics and genomics. It aims to create mathematical models that can predict how a specific genome will express its phenotype in a given environment. By bridging these two fields, researchers can better understand the genetic basis of complex traits and accelerate the development of improved crop varieties through more precise and data-driven breeding strategies.

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79. (A) A rapid, non-destructive spectral signature or proxy trait highly correlated with complex physiological performance or yield
In integrated breeding, a phenomic marker is a sensor-derived trait or spectral signature that serves as a proxy for more complex characteristics. These markers are often faster and easier to measure than the target trait itself, such as yield or drought tolerance. By using these highly correlated proxies, breeders can screen large populations more efficiently and make informed selections based on physiological performance.

80. (B) II and V
Continuous non-destructive phenotyping is characterized by longitudinal studies and time-series data, using various sensors to track plant development. It does not involve killing the plant at intermediate stages, which is a key advantage over traditional methods. While powerful, it does not completely resolve GxE interactions; instead, it provides the detailed data necessary to better understand and model these complex interactions across diverse environments.

81. (A) It improves the phenotypic precision, thereby increasing the statistical power to detect tight linkages between markers and QTLs
Improving phenotyping resolution directly benefits Marker-Assisted Selection by increasing the precision of trait measurements. Higher precision reduces experimental noise, which boosts the statistical power to identify markers that are tightly linked to Quantitative Trait Loci. This results in more reliable genetic associations, enabling breeders to select for desirable alleles with greater confidence and accuracy throughout the breeding cycle.

82. (B) Moving from single-point, labor-intensive manual assessments to automated, multi-dimensional, continuous monitoring
The transition to Next-Generation Phenotyping represents a shift from slow, subjective manual scoring to a more sophisticated, sensor-based approach. Modern platforms allow for the automated and continuous monitoring of multiple trait dimensions simultaneously. This evolution provides a much more detailed and objective understanding of plant growth and physiology, overcoming the limitations of traditional methods that are restricted by human labor and single-time-point measurements.

83. (A) It allows complex traits to be parameterized as a network of basic, independent physiological or anatomical inputs
Defining a phene is crucial for biological modeling because it breaks down complex characteristics into manageable, independent units. By parameterizing traits as networks of these basic inputs, researchers can create more accurate mathematical models of biological pathways. This modular approach allows for a deeper understanding of how individual components contribute to emergent traits, facilitating more precise predictions of plant performance and genetic function.

84. (B) It encompasses the entirety of traits, from molecular profiles (metabolites) to macroscopic structures (yield)
The term "phenome" describes the complete set of an organism's traits across all levels of biological organization. This includes everything from microscopic molecular profiles, such as transcriptomes and metabolomes, to macroscopic features like plant architecture and final crop yield. It is a comprehensive concept that represents the total observable manifestation of an organism's genetics as it interacts with the environment over time.

85. (A) They trigger differential gene expression, resulting in phenotypic plasticity
Varying environments influence genotypes by triggering changes in gene expression. This process allows plants to adapt their growth and development to local conditions, a phenomenon known as phenotypic plasticity. While the underlying DNA sequence remains the same, the differential activation of genes leads to the production of different phenotypes, enabling the plant to survive and thrive in diverse or changing agricultural settings.

86. (B) Precision application of localized water stress in a controlled greenhouse
UAVs are primarily used for field-scale monitoring and high-throughput scanning of outdoor breeding plots. They are ideal for capturing temporal data on canopy development across large areas. However, applying localized water stress in a controlled greenhouse is a task for precision irrigation systems or manual management, not aerial drones, which are designed for observation and data collection in open environments.

87. (A) A composite, geometrically corrected image created by stitching together multiple UAV-captured aerial photos
An orthomosaic is a large, detailed map created by combining numerous individual aerial images captured by a UAV. These images are stitched together and geometrically corrected to remove distortions, resulting in a single high-resolution view that is uniform across the entire area. Orthomosaics are essential in field phenotyping for accurately mapping crop variability and measuring spatial traits over large experimental plots.

88. (A) It primarily captures visible symptoms (like chlorosis), often missing early pre-symptomatic physiological stress
The main limitation of standard RGB imaging is that it only captures light within the visible spectrum. This means it can only detect stress once visible symptoms, such as wilting or yellowing, have already appeared. It often misses the early, pre-symptomatic physiological changes that occur internally, which are better detected using advanced sensors like thermal cameras or hyperspectral devices that measure beyond visible light.

89. (A) Genotype by Environment (GxE) interaction
Genotype by Environment interaction explains why a variety that excels in one climate may perform poorly in another. This phenomenon occurs because the expression of genes is modulated by external factors like temperature and humidity. A genotype's adaptation to temperate conditions might involve traits that are disadvantageous in the tropics, leading to a significant drop in performance when moved between distinct environments.

90. (B) II - IV - I - III
The data flow in a high-throughput phenotyping platform follows a logical sequence. It begins with sensor calibration and image acquisition. The raw images are then pre-processed and stitched together, followed by data analysis and trait extraction. Finally, the extracted phenotypic information is used for decision-making and genomic prediction, completing the cycle from raw observation to actionable biological or breeding insights.

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allowing for more rapid interventions and a better understanding of how plants respond to stressors.

59. (B) Normalized Difference Vegetation Index (NDVI)
The Normalized Difference Vegetation Index is a widely used proxy for plant vigor and green biomass. It is calculated by comparing the reflectance of red light, which is absorbed by chlorophyll, and near-infrared light, which is reflected by healthy leaf tissue. High NDVI values indicate dense, healthy vegetation, making it a standard metric for monitoring crop health and growth in both research and commercial agriculture.

60. (A) Both A and R are true and R is the correct explanation of A.
Thermal infrared imaging is highly effective for detecting water stress because it monitors canopy temperature. When plants experience water deficit, they close their stomata to prevent moisture loss, which simultaneously reduces transpirational cooling. As a result, the canopy temperature increases. This direct link between stomatal regulation and temperature makes thermal imaging a reliable non-invasive method for evaluating plant water status in the field.

61. (A) Stomatal conductance
Thermal imaging provides an indirect measurement of stomatal conductance by capturing canopy temperature. Since transpiration through the stomata cools the leaves, higher temperatures typically indicate reduced stomatal opening. This relationship allows researchers to use thermal data to assess how plants regulate their water loss and respond to environmental stressors like heat and drought, without the need for slow, manual leaf-level measurements.

62. (B) Ambient air temperature and vapor pressure deficit (VPD)
Recording ambient air temperature and vapor pressure deficit is critical when using thermal imaging. Canopy temperature is not an absolute indicator of stress but depends on the surrounding environmental conditions. By accounting for these covariates, researchers can normalize the thermal data and accurately calculate indices like the Crop Water Stress Index. This ensures that observed temperature differences are correctly attributed to plant physiology rather than local weather.

63. (B) Efficiency of Photosystem II and electron transport chain dynamics
Chlorophyll fluorescence imaging is a non-invasive technique used to assess the efficiency of the photosynthetic apparatus. It specifically measures the light energy that is re-emitted by chlorophyll after absorption, which reflects the operating status of Photosystem II. By analyzing these fluorescence patterns, researchers can gain insights into the electron transport chain and overall photosynthetic performance, identifying metabolic disruptions caused by various environmental stressors.

64. (A) $\frac{F_v}{F_m}$
The ratio $\frac{F_v}{F_m}$ is a standard metric in chlorophyll fluorescence imaging that represents the maximum quantum efficiency of Photosystem II. It is measured after a period of dark adaptation and serves as a sensitive indicator of plant stress. A decrease in this value often signals damage to the photosynthetic machinery, providing an early warning of physiological decline before structural or visible symptoms become apparent.

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65. (D) Pathogens alter photosynthetic metabolism before visible lesions appear.
Chlorophyll fluorescence is powerful for early disease detection because many pathogens disrupt a plant's photosynthetic metabolism long before physical symptoms like lesions or chlorosis are visible. By monitoring the efficiency of Photosystem II, researchers can detect localized metabolic changes at the site of infection. This allows for the identification of disease at a pre-symptomatic stage, facilitating more effective management and research.

66. (D) LiDAR (Light Detection and Ranging)
LiDAR technology uses pulsed laser beams to measure distances by calculating the time it takes for the light to reflect off a target. In phenomics, this data is used to create highly accurate 3D models, or point clouds, of plant architecture. LiDAR is exceptionally precise for measuring canopy height, volume, and structural complexity, providing a detailed non-destructive way to evaluate plant growth.

99. (B) To ensure field resilience, a crop must be phenotyped across multiple target environments, not just one location
Because of Genotype by Environment interactions, performance in one setting does not guarantee success in others. To develop resilient and reliable crop varieties, it is essential to evaluate them across multiple locations that represent the diverse conditions of the target growing regions. This multi-environment phenotyping is the only way to accurately characterize GxE interactions and select genotypes with stable and high performance.

100. (A) I and III
LiDAR is an active sensor that generates its own light pulses to create detailed 3D point clouds of plant architecture. This technology is highly effective for non-destructively measuring structural traits like canopy height and estimating biomass. Unlike passive sensors, LiDAR does not rely on solar illumination, allowing it to provide precise geometric data about how plants are structured and how they grow over time.

101. (A) The mathematical profile of phenotypic states produced by a single genotype across an environmental gradient
A reaction norm provides a biological and mathematical description of how a single genotype responds to environmental variation. It maps the range of phenotypes that can be produced across a gradient of conditions, such as different levels of temperature or moisture. This concept is fundamental to understanding phenotypic plasticity and how genes and the environment work together to shape an organism's traits.

102. (C) Tillering capacity in wheat under varying plant densities
Tillering capacity is a highly plastic trait because wheat plants significantly adjust the number of tillers they produce based on available space and resources. In contrast, traits like the number of cotyledons or basic floral architecture are relatively stable. This plasticity allows wheat to optimize its growth and yield potential in response to different planting densities and environmental conditions, demonstrating a flexible adaptive strategy.

103. (C) It separates the plant pixels from the background pixels
In computer vision, image segmentation is the critical process of isolating the object of interest, such as a plant, from everything else in the image. This typically involves removing background elements like soil, shadows, and weeds. By isolating the plant pixels, researchers can accurately calculate phenotypic traits like canopy area and color, ensuring that the resulting data is a true representation of the vegetation.

104. (D) Greenhouse environments fail to capture authentic, complex field-based GxE interactions
A key disadvantage of greenhouse-based "plants to sensors" platforms is that they provide an artificial setting. While they offer high precision and control, they cannot fully replicate the complex and multiple stressors that crops face in the field. Consequently, the findings from greenhouse studies may not always translate directly to field performance, as the intricate interactions between genotypes and natural environments are missing.

105. (A) They act as independent inputs that help mathematically account for non-genetic variance in trait expression
Environmental covariates serve as vital independent variables in phenotypic modeling. By measuring factors like light intensity and soil moisture, researchers can use mathematical models to account for the portion of trait variation caused by the environment. This adjustment helps to reduce noise in the data, allowing for a more accurate estimation of the genotypic contribution to the observed phenotypes.

106. (C) UAVs are typically equipped with root-excavating sensors to map deep root architecture
UAVs are excellent for rapid, non-destructive aerial imaging of crop canopies, but they cannot physically excavate roots. Mapping deep root architecture remains a significant challenge that typically requires ground-based methods or specialized underground sensing. UAV applications are focused on the above-ground parts of the plant, capturing data on canopy cover, height, and health across large field areas from an aerial perspective.

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detect associations. This leads to wider intervals for identified Quantitative Trait Loci and often results in failing to detect genes with smaller effects, significantly hindering the progress of molecular breeding and gene discovery.

43. (A) GWAS relies on exact trait associations; high error leads to false negatives and positives.
Genome-Wide Association Studies depend on finding strong statistical links between genetic markers and specific traits. Accurate phenotyping is critical because even minor errors can lead to false associations or the failure to detect real ones. High-precision trait data reduces background noise, ensuring that the identified genetic variants are truly related to the phenotype, which is essential for successful gene mapping.

44. (A) To automate and scale the capture of accurate, multi-dimensional trait data non-destructively.
Next-Generation Phenotyping aims to modernize crop evaluation by using automation and sensors to collect high-quality trait data. The goal is to move beyond manual methods to a system that can handle large populations non-destructively. This allows for the measurement of multiple trait dimensions simultaneously and repeatedly over time, providing a more comprehensive and efficient way to analyze plant performance and genetics.

45. (B) It allows for the continuous monitoring of developmental trait trajectories over the entire growth cycle
Non-destructive phenotyping offers a significant advantage by allowing researchers to measure the same plant repeatedly throughout its life. This enables the collection of time-series data, which tracks how traits develop and change in response to the environment. Unlike destructive sampling, which provides only a single end-point measurement, non-destructive methods reveal the dynamic growth patterns and physiological transitions of plants.

46. (B) Automation, sensor-based measurement, high spatial and temporal resolution
High-throughput phenotyping platforms are built on the principles of automation and advanced sensing. These systems use various sensors to capture detailed information about plant structure and function with high precision. By combining high spatial resolution with frequent measurements over time, these platforms provide the scale and accuracy needed to match the speed of modern genomics and accelerate agricultural research.

47. (D) Plants are grown on automated conveyor belts and transported to central stationary imaging cabinets
In the "plants to sensors" paradigm, the plants are mobile while the sensors remain stationary. Typically, this setup is used in greenhouses where plants in pots are placed on automated conveyor belts. At scheduled intervals, the belts transport each plant to a centralized imaging station or cabinet where various sensors capture high-resolution data before returning the plant to its growing area.

48. (B) Controlled-environment automated greenhouses
The "plants to sensors" design is most frequently implemented in automated greenhouses. This environment allows for the precise control of growing conditions while facilitating the use of conveyor systems to move plants to stationary sensing equipment. This setup is ideal for detailed physiological studies and initial genetic screenings, providing high-quality data under consistent conditions that are difficult to achieve in open fields.

49. (A) The artificial environment may not perfectly replicate complex real-world field conditions (GxE limitations)
A major limitation of greenhouse-based "plants to sensors" platforms is the gap between controlled conditions and real-world agriculture. While greenhouses provide high precision, the artificial environment cannot fully replicate the complex interactions between genetics and the diverse stresses found in the field. This can limit the applicability of the findings, as genotypes may perform differently when exposed to authentic outdoor conditions.

50. (A) I, II and IV
The "sensors to plants" paradigm involves moving measurement devices to stationary plants, primarily in field settings. This approach utilizes technologies like ground-based phenomobiles, tractors, and gantries to evaluate crops under natural environmental conditions. By bringing the sensors to the field, researchers

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115. (C) It aims to capture phenotypic expression in authentic agronomic field environments using mobile sensor platforms
The "sensors to plants" paradigm is focused on evaluating crops in their natural field settings. This approach uses mobile platforms, such as drones or tractors, to bring advanced sensors directly to the stationary plants. By phenotyping in these authentic agronomic environments, researchers can better understand how genotypes respond to real-world conditions, including the complex interactions between genetics and the local environment.

116. (D) Phenomobiles cause soil compaction and have lower spatial repeatability than gantries
While phenomobiles offer flexibility, they have logistical disadvantages compared to gantries. Tractors are heavy and can cause significant soil compaction, which may negatively affect plant growth and introduce experimental bias. Additionally, they lack the extreme spatial precision of rail-mounted gantries, making it harder to repeatedly scan the exact same millimeter-scale area over the growing season for detailed time-series analysis of individual plants.

117. (A) The multidimensional space encompassing all measurable phenotypic traits of an organism
The phenome is a comprehensive concept that represents the entire collection of observable traits of an organism. It is a multidimensional space because it includes characteristics from across all levels of biological organization, from molecular profiles to macroscopic structures. The phenome is the ultimate physical and biochemical manifestation of the genome, reflecting its dynamic interaction with the environment throughout the organism's entire life cycle.

118. (C) The capacity to track individual plant physiological changes dynamically throughout stress and recovery
Non-destructive imaging is uniquely powerful for studying stress response because it allows for continuous monitoring of the same individual. Researchers can track exactly how a single plant reacts as drought conditions intensify and how it recovers after rewatering. This dynamic, temporal data provides much deeper insights into resilience mechanisms than destructive sampling, which can only provide a single snapshot of different individuals.

119. (B) It causes a single genotype to produce multiple distinct phenotypes depending on the specific environmental context
Phenotypic plasticity complicates the gap between the genome and phenome by introducing a many-to-one relationship. Because a single genotype can express different phenotypes in different environments, the genomic sequence alone cannot perfectly predict plant performance. This variability means that researchers must evaluate genotypes across multiple conditions to fully understand their adaptive range and the context-dependent nature of their phenotypic expression.

120. (B) P-4, Q-2, R-1, S-3
Key concepts in phenomics involve both data processing and biological theory. Image segmentation isolates plant pixels from the background, while ground truthing uses manual measurements to validate sensor-based models. A point cloud is the 3D data generated by LiDAR, representing plant structure. Finally, a reaction norm is a graphical tool used to map how a genotype's phenotypic expression changes across different environmental conditions.

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121. (B) It detects the reduction in transpirational cooling caused by stomatal closure
Thermal infrared cameras measure the infrared radiation emitted by the plant canopy, which is used to calculate surface temperature. This is a direct proxy for water status because plants close their stomata during drought to conserve water, which reduces transpiration. Since transpiration is a cooling process, its reduction leads to an increase in canopy temperature, making thermal imaging a sensitive non-invasive tool for detection.

122. (B) Automating the counting of wheat spikes from complex UAV field images using Convolutional Neural Networks
Deep learning, particularly Convolutional Neural Networks, is widely used to automate difficult visual tasks in phenomics. A classic application is the automated identification and counting of specific organs, like wheat spikes, from high-resolution aerial images. These algorithms can learn to recognize complex spatial patterns and features, providing a fast and objective way to extract traits that were previously very time-consuming to measure manually.

the results of QTL mapping. By reducing experimental noise and increasing measurement precision, the statistical power to detect genetic associations is boosted. This leads to more accurate mapping with narrower intervals for major genomic regions and allows for the identification of smaller-effect QTLs that were previously hidden by background variation, providing a more detailed understanding of the genetic control of traits.

185. (B) Minor localized depressions in soil topography causing uneven water pooling
Micro-environmental variations are small-scale differences within a field that can affect plant growth. An example is a minor depression in the soil that leads to uneven water accumulation. Even in a seemingly uniform plot, these localized factors cause plants with the same genotype to express different phenotypes. Recognizing and accounting for these subtle micro-variations is essential for accurate phenotyping and for isolating the true genetic differences between plant varieties.

186. (B) By using algorithms to segment the image, recognize features, and mathematically calculate metrics
Computer vision transforms raw sensor data into quantifiable traits through a structured digital process. Specialized algorithms are used to segment the image, isolating the plant from the background. The system then identifies and measures specific features, such as size, shape, and color. By mathematically calculating these metrics, computer vision provides an objective and high-throughput way to extract detailed phenotypic information that can be used for biological research and breeding decisions.

187. (B) It describes the flow of genetic information from DNA to RNA to functional proteins that dictate basic phenes
The central dogma is the foundational framework for understanding how the genome influences the phenome. It outlines the flow of information from DNA to RNA and then to proteins. These proteins are the functional molecules that execute the biological processes forming basic phenes. By describing this molecular pathway, the central dogma provides the essential bridge for understanding how genetic instructions are translated into the building blocks of an organism's traits.

188. (B) A high-density 3D point cloud generated by terrestrial LiDAR scanning
For an accurate estimation of 3D architecture, LiDAR is the most effective technology. It uses laser pulses to create a dense point cloud that represents the physical geometry and volume of the plant. Unlike 2D images or spectral indices, LiDAR provides direct measurements of how a plant occupies three-dimensional space. This allows for the precise quantification of canopy volume and architectural complexity, providing a detailed non-destructive view of structural development.

189. (A) Serving as a rapid, high-throughput, sensor-derived proxy trait to indirectly select for complex physiological performance or yield
A phenomic marker is a sensor-derived trait, such as a spectral signature or a structural metric, that serves as a proxy for more complex characteristics. These markers are often faster and easier to measure than the target trait itself. By identifying markers that are highly correlated with performance or yield, breeders can screening large populations more efficiently, making informed selections based on rapid, high-throughput measurements rather than slow, traditional evaluations.

190. (A) II - IV - I - III
Developing a machine learning model for trait extraction follows a clear developmental sequence. It begins with acquiring raw images and manually annotating "ground truth" data for training. Mathematical features are then extracted from these images to teach the model. The algorithm is trained using this information and, once validated, is deployed to automatically extract traits from new, unannotated images, providing an efficient and automated way to process large phenomic datasets.

191. (B) A breeding program sequences 10,000 lines in a week but takes 5 years to manually measure their drought tolerance
The phenotyping bottleneck is clearly illustrated by the time disparity between genomic sequencing and trait evaluation. While modern technology allows for the rapid sequencing of thousands of individuals, the process of accurately measuring complex traits like drought tolerance in the field remains slow and labor-intensive. This imbalance prevents researchers from quickly linking genetic variation to actual performance, highlighting

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131. (B) To ensure precise spatial accuracy and geo-referencing when stitching aerial images into an orthomosaic map
Ground Control Points are essential for ensuring the spatial accuracy of UAV data. These are physical markers placed in the field with known coordinates. During image processing, GCPs are used to geometrically correct the aerial photos and align them precisely. This ensures that the final orthomosaic map and the resulting phenotypic data are correctly geo-referenced, allowing for accurate spatial analysis and temporal comparisons.

132. (A) The transcriptome and proteome
The transcriptome and proteome act as the immediate functional links between the genotype and the observable phenotype. The transcriptome represents the active set of gene transcripts, while the proteome consists of the proteins that execute cellular functions. Together, they bridge the gap from genetic information to metabolic activity, directly influencing the development of traits and the organism's response to the environment at a molecular level.

133. (B) It is a macroscopic emergent phenotype resulting from the synergistic interaction of numerous elementary phenes like root depth and stomatal control
Drought tolerance is an emergent trait that cannot be reduced to a single biological unit. It arises from the combined, synergistic action of many underlying physiological and morphological phenes, such as root architecture, stomatal regulation, and osmotic adjustment. This complexity means that tolerance is the macroscopic result of many interacting parts, each influenced by both genetics and the environment throughout the plant's development.

134. (B) Pleiotropy
Pleiotropy is the phenomenon where a single genetic locus affects multiple, seemingly unrelated traits. In agriculture, this could mean one gene influences both an underground trait like root hair length and an above-ground trait like flowering time. Understanding these pleiotropic effects is vital because a change in one gene can have broad consequences across the plant's entire phenotype, affecting multiple aspects of its growth and performance.

135. (A) It directly measures internal cellular chlorophyll content
LiDAR is a structural sensor that uses laser pulses to measure distances and create 3D models of plant architecture. It is excellent for non-destructively estimating traits like canopy height and biomass. However, it cannot measure internal biochemical components like chlorophyll content, which requires spectral sensors like multispectral or hyperspectral cameras. LiDAR's primary strength is its ability to capture the physical geometry and volume of the vegetation.

136. (B) A measured variable like temperature or soil moisture used to account for environmental variance
Environmental covariates are non-genetic factors that are recorded during phenotyping to help explain trait variation. By measuring variables like ambient temperature, solar radiation, and soil moisture, researchers can use statistical models to separate environmental effects from true genetic differences. Accounting for these covariates is essential for improving the precision of phenotypic data and for accurately modeling how plants respond to their surroundings.

137. (B) Localized changes in soil can cause phenotypic variations that mask genetic differences.
Micro-environmental variations are a major challenge because they introduce noise into phenotypic data. Small differences in soil quality or water availability within a single plot can cause plants with identical genotypes to grow differently. If these variations are not accounted for, they can mask the true genetic differences between varieties, leading to inaccurate assessments of their performance and potential in breeding programs.

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138. (B) It minimizes the experimental error variance (V_e), allowing for the statistically robust identification of smaller-effect genomic loci
Accurate high-throughput phenotyping improves QTL mapping by providing high-quality, precise trait data. By reducing measurement error and accounting for environmental noise, HTP increases the signal-to-noise ratio in genetic studies. This improved precision allows researchers to identify genomic regions with smaller effects that would otherwise be hidden, leading to a more detailed and accurate understanding of the genetic control of complex traits.

large populations and over time, ensuring that phenotypic data is accurate and reliable, which is essential for modern data-driven breeding and research.

155. (B) A high-clearance phenomobile driving over stationary field plots to capture hyperspectral canopy data
The "sensors to plants" paradigm is clearly shown when mobile sensing platforms are brought to stationary plants in a field. A phenomobile, equipped with advanced sensors, drives through experimental plots to collect high-resolution data on the crop's development. This method allows researchers to evaluate plant performance under natural conditions while maintaining a high level of throughput and capturing the authentic phenotypic responses of the crop in its environment.

156. (A) Gantries offer near-perfect temporal repeatability over the exact same sub-millimeter spatial coordinate, whereas UAVs are subject to flight path variations
A major distinction between field gantries and UAVs is the level of spatial precision. Because gantries move on fixed rails, they can return to the exact same sub-millimeter location for every measurement. This perfect repeatability is ideal for detailed studies of individual plants over time. In contrast, UAVs are subject to variations in flight paths and wind, making it more challenging to achieve the same level of precise spatial alignment across temporal scans.

157. (B) The specific response trajectory of a distinct genotype's phenotype across a gradient of environmental conditions
A reaction norm is a graphical representation of phenotypic plasticity. it shows how the trait value of a specific genotype changes in response to an environmental gradient, such as different temperatures or nutrient levels. By mapping this response trajectory, researchers can visualize the sensitivity of a genotype to environmental variation, which is crucial for understanding adaptation and for selecting varieties that perform well in specific target environments.

158. (D) It operates in a vacuum, entirely independent of environmental feedback and epigenetics
The pathway from genome to phenome is not an isolated process. It is constantly influenced by environmental feedback and epigenetic modifications that regulate gene expression. Factors like stress can trigger changes in molecular activities, from transcription to post-translational modification, which in turn alter the plant's development. Asserting that this pathway is independent of external influences is incorrect, as the environment is a fundamental shaper of an organism's traits.

159. (B) Separating the pixels representing crop canopy from those representing background soil, shadows, and weeds
Image segmentation is a vital step in processing aerial drone images. Its goal is to isolate the pixels that belong to the crop canopy from non-target elements like the soil, shadows, and surrounding weeds. By accurately isolating the vegetation, researchers can calculate important metrics like canopy cover and color without interference from the background, ensuring that the resulting phenotypic data is precise and meaningful.

160. (A) Both A and R are true and R is the correct explanation of A.
Deep learning algorithms, particularly Convolutional Neural Networks, have become essential in modern phenomics because of their power to process unstructured image data. These algorithms are specifically designed to recognize complex spatial patterns, which allows them to automatically identify and quantify traits within massive datasets. This automation overcomes the limitations of manual feature extraction, enabling more efficient and accurate analysis of the large-scale imagery produced by HTP platforms.

161. (A) Electron transport rate and photosynthetic efficiency of Photosystem II
Chlorophyll fluorescence imaging is highly precise for measuring the internal workings of photosynthesis. It specifically assesses the efficiency of Photosystem II and the rate of electron transport by capturing the light re-emitted by chlorophyll. This non-invasive measurement provides a direct window into the plant's metabolic health, allowing researchers to detect physiological changes and stress-induced disruptions at a very fine level of detail.

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invasively screen for genotypes with better water-management strategies.

147. (B) The lack of high-throughput, accurate, and cost-effective methods to evaluate complex plant traits at the scale of genomic data generation
The phenotyping bottleneck is caused by a massive imbalance between genomic and phenomic technologies. While sequencing has become incredibly fast and cheap, the methods for measuring traits have not advanced at the same rate. This lack of efficient, high-scale phenotyping tools prevents researchers from fully utilizing genetic data, as they cannot quickly and accurately characterize the physical traits needed to understand gene function and performance.

148. (A) Phenotypic plasticity
Phenotypic plasticity is the biological principle that allows a single genotype to produce various phenotypes in response to different environmental conditions. This flexibility is a key adaptive mechanism, enabling plants to adjust their growth and physiology to survive in changing or diverse surroundings. Plasticity is a fundamental aspect of the relationship between genes and the environment, ensuring that trait expression is not strictly fixed but context-dependent.

149. (B) The fundamental, elementary unit of a biological phenotype
A phene is defined as the most basic, irreducible unit of a phenotype. It represents an elementary biological component, such as a specific anatomical feature or a fundamental physiological process. Just as a gene is a basic unit of inheritance, a phene is a basic unit of observation. Understanding these building blocks is essential for deconstructing and modeling the complex traits that are important in agriculture and biology.

150. (B) IV only
Genotype by Environment interaction is a central concept in breeding, meaning that variety performance varies across locations and complicating the development of broadly adapted crops. GxE interactions can be modeled using data from multi-location trials and highlight the importance of localized environmental factors. The idea that genotypes are immune to environmental changes is incorrect, as phenotypes are the result of the constant interplay between genes and surroundings.

151. (B) A phene isolates an indivisible physiological or anatomical mechanism, reducing the confounding effects found in aggregated complex traits
Using the concept of a phene is scientifically superior because it focuses on simple, fundamental units. Complex traits like yield are influenced by many interacting factors, making them difficult to model accurately. By isolating individual, irreducible phenes, researchers can reduce this complexity and focus on specific biological mechanisms. This modular approach provides a clearer understanding of the genetic basis of traits and facilitates more precise biological predictions.

152. (A) Multispectral and hyperspectral imaging
Multispectral and hyperspectral imaging are designed to capture electromagnetic radiation beyond what the human eye can see. These technologies record reflectance in key regions like the near-infrared and shortwave infrared, which are sensitive to a plant's internal structure and water content. By using these non-visible bands, these imaging techniques can detect physiological changes and stress symptoms that are invisible in standard visible-light photography or manual scoring.

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153. (B) Genotypic variance
In the phenotypic variance equation, V_g represents the portion of the total variation that is caused by genetic differences between individuals. This genotypic variance is a fundamental component for breeders, as it indicates the amount of variation that is inheritable. Understanding V_g relative to environmental and interaction variances is essential for calculating heritability and for determining the potential for genetic gain through selection in breeding programs.

154. (A) By replacing subjective human estimations with objective, highly repeatable, quantitative sensor-derived data
High-throughput phenotyping platforms overcome the limitations of manual scoring by providing a more objective way to measure traits. Human evaluators are prone to subjectivity and inconsistency, whereas sensors provide standardized, quantitative data. These platforms allow for highly repeatable measurements across

139. (C) Chlorophyll fluorescence imaging
Chlorophyll fluorescence imaging is the most appropriate technique for monitoring Photosystem II efficiency over time. This non-invasive method captures the light energy re-emitted by chlorophyll, which directly reflects the status of the photosynthetic electron transport chain. By tracking these fluorescence patterns, researchers can dynamically assess how plants manage light energy and how their photosynthetic performance is affected by environmental stress throughout their development.

140. (B) Genome → Proteome → Fundamental Phene → Emergent Complex Trait
The biological hierarchy linking genetics to agriculture begins with the genome. This genetic blueprint is translated into the proteome, which executes the functions that form fundamental phenes, such as specific anatomical or physiological units. These phenes then interact synergistically to produce emergent complex traits like yield or resilience. This sequence illustrates the multi-level organization required to transform genetic information into macroscopic crop performance.

141. (B) GS uses genome-wide markers to predict breeding values for polygenic traits, using phenomic data for training.
Genomic Selection is superior for complex traits because it considers the entire genome rather than just a few major loci. It uses a training population where both genomic and high-resolution phenomic data are known to create predictive models. These models can then estimate the breeding values of new individuals based on their genetic markers alone, allowing for more accurate and efficient selection for multifaceted polygenic traits.

142. (B) Leaf Area Index (LAI) or canopy cover percentage
Leaf Area Index and canopy cover are key metrics for understanding a plant's ability to intercept light. These traits can be accurately extracted from RGB images and serve as proxies for the plant's total photosynthetic surface area. By measuring how much of the ground is covered by vegetation, researchers can estimate how efficiently the crop is capturing solar energy, which is a fundamental driver of biomass production and yield.

143. (B) Growth curves must be inferred from different individuals killed at different timepoints, introducing immense individual-to-individual variance
Traditional destructive sampling is problematic for studying growth because it requires killing a different set of plants at each timepoint. Since no two plants are identical, this introduces significant individual-to-individual variance into the data, which can obscure true developmental trends. This method prevents researchers from tracking the same individual's progress over time, making it much more difficult to accurately model dynamic growth curves.

144. (B) The sequential computational workflow that acquires raw sensor data, processes it, and extracts quantifiable biological metrics
A phenomic pipeline is the digital architecture used to transform raw observations into useful data. It consists of a series of automated steps, including image pre-processing, segmentation, feature extraction, and trait calculation. This computational workflow is essential for handling the large volumes of data generated by high-throughput sensors, ensuring that the results are consistent, objective, and ready for biological or genetic analysis.

145. (A) To act as a dynamic platform carrying specialized sensors for rapid, high-throughput spatial phenotyping at the canopy level
UAVs serve as versatile platforms for carrying various sensors over agricultural fields. Their main role is to facilitate rapid and non-destructive phenotyping of large areas from above. By capturing high-resolution data on canopy structure and health, UAVs allow researchers to monitor crop development and spatial variability at a scale and speed that is impossible with manual ground-based methods, accelerating agricultural research.

146. (A) Tolerant genotypes maintain transpiration to keep canopies cool under stress.
Thermal imaging helps identify drought tolerance by monitoring canopy temperature. Tolerant genotypes often have mechanisms that allow them to maintain some level of transpiration even under stress, which keeps their leaves cooler. In contrast, susceptible plants may close their stomata more completely, leading to a sharp rise in temperature. This difference in thermal signature allows researchers to non-

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162. (B) It sharply reduces phenotypic background noise, increasing the statistical power to detect true associations between markers and traits
Precise phenomic data is a powerful asset for Genome-Wide Association Studies. By using high-resolution, accurate trait measurements, researchers can significantly reduce the background noise caused by experimental error. This cleaner data increases the signal-to-noise ratio, providing the statistical power needed to identify true linkages between genetic markers and traits. This leads to more reliable gene discovery and a better understanding of the genetic architecture of complex characteristics.

163. (B) Elementary physiological phenes interact to produce complex macroscopic phenotypes that cannot be easily predicted by studying each phene in isolation
Phene synergism leads to the emergence of complex traits that are more than just a simple sum of their parts. When different elementary physiological phenes interact, they create outcomes that cannot be fully understood by looking at each component alone. This non-additive behavior is a fundamental challenge in biological modeling, as it requires a systems-level understanding of how diverse biological processes work together to shape an organism's performance.

164. (B) High-resolution 3D geometrical structure and volume of the crop canopy
Terrestrial LiDAR systems are designed to capture the physical structure of objects in three dimensions. In agricultural settings, they emit laser pulses to create dense point clouds that represent the detailed geometry and volume of the crop canopy. This data is essential for non-destructively measuring structural traits like biomass and plant architecture, providing a highly accurate alternative to 2D imaging for understanding how plants occupy space.

165. (B) The specific variance arising when different genotypes respond differently to the same environmental changes
The term $V_{\{\geq\}}$ represents the interaction between genetics and the environment. It captures the reality that the effect of an environmental change can differ depending on the genotype of the individual. This interaction means that the performance ranking of different varieties can switch across environments, making it a critical factor for breeders who must develop crops that are either broadly adapted or specifically suited to certain locations.

166. (A) Thermal Camera - Stomatal conductance proxy
Different sensors are linked to specific physiological or structural traits. A thermal camera measures canopy temperature, which serves as a proxy for stomatal conductance because transpirational cooling is directly tied to stomatal opening. In contrast, LiDAR is used for structural measurements, not biochemistry, and standard RGB cameras are focused on above-ground morphology rather than sub-surface roots. Matching the right sensor to the target trait is essential for accurate phenotyping.

167. (B) A specific rice genotype dramatically increases its root depth exclusively under severe water deficit conditions
Phenotypic plasticity is clearly demonstrated when a single genotype changes its trait expression in response to the environment. For example, a rice plant that only increases its root depth when it detects water stress is showing a flexible adaptive response. This ability to adjust development based on external cues allows the plant to survive under difficult conditions, illustrating how the same genetic code can produce different biological outcomes.

168. (B) It captures exactly where within a field, and precisely when during the growth cycle, critical physiological changes occur
High spatial and temporal resolution provide a detailed map of plant development in both space and time. Spatial resolution shows the variation within a field, while temporal resolution tracks changes throughout the growth cycle. Together, these measurements allow researchers to pinpoint exactly when and where critical physiological shifts happen, providing the high-resolution data needed to understand dynamic crop responses to environmental stress and to model complex growth patterns.

169. (B) To improve breeding value predictions for complex traits by training models with high-dimensional, precise environmental data
The integration of phenomics and genomic selection aims to make breeding more accurate and efficient. By using high-dimensional, precise phenotypic and environmental data

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123. (C) The size of the smallest detectable feature
Spatial resolution is a fundamental parameter in imaging that determines the amount of detail captured. It refers to the size of the smallest object or feature that can be clearly distinguished in an image. In crop phenotyping, high spatial resolution is necessary to identify and measure fine-scale traits, such as individual leaves or disease spots, ensuring that the extracted data is accurate and detailed.

124. (D) Mapping takes one month, but accurately assessing drought tolerance in the field takes multiple years
The phenotyping bottleneck is exemplified by the time difference between genomic discovery and trait validation. While genetic mapping can be done relatively quickly, accurately evaluating complex traits like drought tolerance in the field requires several years of multi-location trials. This disparity in speed means that trait evaluation is the slowest part of the breeding process, highlighting the need for more efficient and high-throughput phenotyping.

125. (B) Genome → Transcriptome → Proteome → Phenome
The flow of biological information follows a hierarchical path from the inherited genetic sequence to the physical organism. The genome is transcribed into the transcriptome, which is then translated into the proteome. These proteins drive metabolic and structural processes that ultimately result in the observable phenome. This sequence illustrates how genetic instructions are progressively transformed into the functional and structural traits of a plant.

126. (A) Plant developmental stages are highly dynamic and transient traits might be missed with infrequent sampling
High temporal resolution is essential because plant development is a fast-moving process. Many important physiological changes and phenological transitions, such as the exact timing of flowering or the peak of a stress response, are transient. Frequent monitoring ensures that these critical moments are captured, providing a complete and detailed record of the plant's life cycle that would be lost with only a few measurements.

127. (A) It is subjective and lacks the continuous quantitative resolution provided by digital image analysis
Visual manual scoring is limited by human subjectivity and a lack of precision. Different evaluators may give different scores to the same plant, and manual scales are often too coarse to capture subtle variations in resistance. In contrast, digital image analysis provides objective, continuous, and highly repeatable measurements, offering a more accurate and reliable way to quantify disease severity and other complex phenotypic traits.

128. (B) Utilizing automated conveyor belts to transport potted plants to stationary imaging cabinets
The "plants to sensors" paradigm is typically found in automated greenhouses. In this setup, plants are grown in pots on conveyor belts that move them to a central location for sensing. This allows the plants to be brought to high-precision stationary sensors, which can capture detailed data under consistent conditions. It is a highly efficient way to phenotype large numbers of plants throughout their growth.

129. (A) By precisely mapping physiological phenes to specific QTLs, breeders can select for desirable alleles earlier and more reliably without waiting for final yield evaluation
Integrating genomic and phenomic data improves Marker-Assisted Selection by identifying the specific physiological building blocks of complex traits. By linking these elementary phenes to genetic markers, breeders can select for superior alleles at an early stage. This reduces the need to wait for final yield measurements, making the breeding process faster and more efficient by focusing on the underlying mechanisms of performance.

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130. (A) I, II and IV
Multispectral imaging is a versatile tool that captures visible light along with key invisible bands like near-infrared. It is the primary technology used for calculating important vegetation indices like NDVI, which reflect plant health. Because multispectral sensors are relatively light and compact, they are easily mounted on UAVs, enabling researchers to collect detailed canopy data across large field areas efficiently and non-destructively.

for characterizing strict genetic responses that might be masked by the variability of a natural field setting.

177. (A) Using the reflectance values of near-infrared (NIR) and red light: $\frac{NIR - Red}{NIR + Red}$

The Normalized Difference Vegetation Index is calculated using the specific reflectance patterns of green plants. Healthy vegetation reflects most near-infrared light while absorbing red light for photosynthesis. By using the difference and sum of these two bands, NDVI provides a normalized value that reflects the health and density of the vegetation. This simple but powerful formula is a standard tool for monitoring crop vigor and biomass in agricultural research.

178. (D) Genotype is the inherent genetic instructions; phenome is the total observable expression across environments

Genotype and phenome are related but distinct concepts. The genotype is the internal genetic code that an organism inherits, providing the potential for its development. The phenome, in contrast, is the actual physical and biochemical manifestation of those instructions as they interact with the environment over time. The phenome is dynamic and includes all measurable traits across multiple biological scales, representing the organism's total observable expression throughout its life.

179. (A) The traits are highly polygenic and heavily influenced by complex GxE interactions and phene synergism

Pinpointing genes for complex traits like yield is difficult because they are controlled by many genes, each with a small effect. Additionally, these polygenic traits are strongly influenced by interactions between genetics and the environment, as well as by the non-additive synergies between underlying phenes. This complexity means that the final phenotype is not a simple direct result of a few genes, but an emergent outcome of a multifaceted and dynamic biological system.

180. (B) I and III

Early disease detection is possible using advanced phenotyping techniques like chlorophyll fluorescence. This method can identify metabolic disruptions, such as a drop in Photosystem II efficiency, before any physical lesions become visible to the naked eye. By monitoring these subtle physiological changes, researchers can detect stress at a pre-symptomatic stage. This approach provides a much more sensitive and earlier warning of infection than traditional methods that rely on macroscopic observations of tissue damage.

181. (B) A specific, interacting cascade of molecular events executing a distinct biological function

A biological pathway is a coordinated series of molecular interactions, such as those involving genes, RNA, and proteins, that work together to perform a specific function. These pathways bridge the gap between the genome and the phenome by translating genetic instructions into metabolic activity and structural development. Understanding these interactive cascades is essential for modeling how genetic variation leads to the diverse traits and functions observed in living organisms.

182. (B) Uprooting a plant, washing its roots, drying it in an oven, and weighing its total biomass

Destructive phenotyping involves methods that require the permanent removal or killing of the plant to take measurements. Uprooting a plant to measure its biomass is a classic example. While this provides accurate physical data, it prevents the researcher from tracking the same individual over time. In contrast, non-destructive methods like thermal imaging or chlorophyll fluorescence allow for continuous monitoring without harming the plant, enabling the study of dynamic trait development.

183. (B) They provide near-perfect spatial repeatability, scanning the exact same micro-coordinate over the growing season

Mobile field gantries are rail-mounted structures that offer exceptional spatial precision. Because they move on fixed tracks, they can return to the exact same millimeter-scale coordinate for every scan throughout the season. This high level of repeatability is a major advantage over manual or tractor-based methods, as it allows for the precise tracking of individual plant growth and architectural changes with minimal spatial error and no soil disturbance.

184. (D) Noise drops, shrinking QTL intervals and identifying previously masked minor QTLs

Replacing low-quality phenotypic data with high-resolution HTP data significantly improves

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to train models, breeders can better predict the breeding value of individuals for complex traits. This integrated approach allows for more informed selection decisions based on a deeper understanding of how genotypes interact with their surroundings, ultimately accelerating the development of improved crop varieties.

170. (A) P-2, Q-4, R-1, S-3
Phenotyping methods vary in their characteristics and applications. Visual scoring is a subjective qualitative assessment, while destructive sampling provides absolute biomass but prevents temporal tracking of individuals. Non-destructive HTP allows for continuous time-series evaluation of traits. Aerial phenomics, using technologies like drones, facilitates high-throughput imaging at a field scale. Understanding these differences is essential for choosing the most appropriate method for specific research or breeding objectives.

171. (A) A single gene mutation altering both final grain size and early seedling vigor simultaneously
Pleiotropy is a common phenomenon in agriculture where a single gene influences multiple traits. For example, a genetic change that impacts both grain size and seedling vigor shows how one molecular mechanism can have broad effects across different stages of plant development. Recognizing these pleiotropic relationships is important for breeders to understand how selecting for one desirable trait might inadvertently lead to changes in other aspects of the plant's phenotype.

172. (B) Hyperspectral sensors record reflectance across hundreds of narrow contiguous spectral bands per pixel
Hyperspectral sensors generate huge amounts of data because they capture information across a vast number of wavelengths. While a standard RGB camera only records three broad bands, a hyperspectral sensor measures hundreds of narrow, contiguous bands for every pixel. This high spectral resolution provides a detailed "fingerprint" of the target, but it also results in a much larger data volume that requires specialized storage and advanced computational processing.

173. (A) It provides manual measurements to validate and calibrate the predictive models derived from indirect sensor data
Ground truthing is a critical step for ensuring the accuracy of high-throughput phenotyping. It involves collecting precise manual measurements that serve as a reference for the sensor data. By comparing the indirect sensor outputs to this "ground truth," researchers can calibrate their models and validate the accuracy of their automated trait extractions. This process is essential for building reliable machine learning models that can be used for large-scale phenomic analysis.

174. (A) Total grain yield per hectare
Total grain yield is a classic emergent macroscopic phenotype. It is the final result of countless underlying physiological and morphological processes, such as photosynthesis, nutrient uptake, and flowering time, all interacting with the environment over the entire growing season. Unlike simple traits like xylem diameter or localized photosynthetic efficiency, yield cannot be reduced to a single biological unit, as it represents the cumulative performance of the whole crop system.

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175. (B) It perfectly scales with the rapid output of Next-Generation Sequencing
Conventional phenotyping is often a bottleneck in modern science because it cannot keep up with the speed of genomic technologies. While sequencing has become incredibly fast and automated, traditional methods like manual measuring and destructive sampling remain slow and labor-intensive. This disparity in scale means that researchers can sequence far more individuals than they can accurately phenotype, highlighting the urgent need for high-throughput, automated trait evaluation systems to bridge this gap.

176. (D) It provides highly precise control over environmental variables, isolating strict genotypic responses
A major benefit of automated greenhouse platforms is the ability to precisely control the growing environment. By maintaining consistent levels of light, temperature, and water, researchers can minimize environmental noise and more effectively isolate the genotypic contribution to trait expression. This high level of control is ideal for detailed physiological studies and

the need for more efficient and high-throughput phenotyping systems.

192. (A) It breaks down highly complex traits into their elemental, physiological, or structural building blocks
The concept of a phene is critical because it allows for a reductionist approach to understanding complex traits. By deconstructing a multifaceted characteristic like yield into simpler, irreducible components, researchers can focus on specific physiological or structural mechanisms. This modular view simplifies genetic mapping and biological modeling, providing a clearer and more detailed understanding of how individual parts contribute to the overall performance and resilience of a crop.

193. (B) Higher spatial resolution captures finer anatomical details, enabling the precise segmentation of specific plant organs
Spatial resolution is a key factor in phenotyping accuracy as it determines the level of detail in the images. Higher resolution allows the sensor to capture finer anatomical features, which is essential for accurately isolating and measuring specific plant organs like leaves or flowers. This precision in segmentation ensures that the resulting phenotypic data is a true and detailed representation of the plant's physical structure, enabling more accurate biological analysis.

194. (A) Transitions are highly dynamic; infrequent sampling will likely miss the exact timing
High temporal resolution is vital because plant development involves many fast-moving and transient stages. Phenological transitions, such as the onset of flowering or the peak of a stress response, can happen quickly. If measurements are taken too infrequently, these critical moments may be missed. Continuous or frequent monitoring ensures a complete record of the plant's life cycle, providing the detailed temporal data needed to accurately model growth and development.

195. (A) The interaction of elemental phenes producing an emergent complex phenotype not predictable by simple additive effects
Phene synergism refers to the non-additive interactions between basic biological units. It occurs when multiple elementary physiological or morphological phenes work together to produce a complex, macroscopic phenotype, such as yield or vigor. These interactions create emergent properties that are more than just the sum of their individual parts, making it essential for researchers to understand the systems-level coordination of these components when modeling plant performance and genetic function.

196. (B) It relies on the distinct differential reflectance of red light and near-infrared light
Multispectral imaging calculates the Normalized Difference Vegetation Index by measuring how plants reflect red and near-infrared light. Green vegetation absorbs red light for photosynthesis but strongly reflects near-infrared light due to its internal leaf structure. By comparing the reflectance values of these two bands, the NDVI formula provides a reliable measure of green biomass and plant vigor, making it a standard tool for monitoring crop health non-destructively in agricultural research.

197. (B) They aim to statistically link specific genetic variants (SNPs) across the entire genome with precisely measured phenotypic traits
Genome-Wide Association Studies are designed to identify the genetic basis of traits by searching for statistical links between DNA markers and physical characteristics. By scanning the entire genome of a diverse population, GWAS can pinpoint specific genetic variants that are associated with variations in precisely measured phenotypes. This approach is powerful for discovering the genes that control complex traits and for understanding the genetic architecture of important agricultural characteristics.

198. (A) Ambient air temperature and Vapor Pressure Deficit (VPD)
Accurate thermal imaging for stress detection requires simultaneous measurement of ambient air temperature and vapor pressure deficit. Canopy temperature is not an absolute indicator but is influenced by these surrounding conditions. By accounting for these covariates, researchers can normalize the thermal data, ensuring that any observed temperature increases are correctly interpreted as physiological responses to water deficit rather than just fluctuations in the local weather or air temperature.

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214. (C) Normalized Difference Vegetation Index (NDVI)
The Normalized Difference Vegetation Index is a standard metric in remote sensing that utilizes the differential reflectance of red and near-infrared light. Healthy plants absorb red light for photosynthesis but reflect near-infrared light due to their internal cellular structure. By calculating the ratio between these two bands, NDVI provides a normalized measure of vegetation greenness and vigor, serving as a reliable proxy for plant health and biomass in both research and commercial agriculture.

215. (A) They scan massive field trials rapidly and non-destructively without causing soil compaction
UAVs provide a significant advantage in aerial phenomics because of their speed and lack of ground contact. They can scan large experimental fields quickly, capturing detailed canopy data without damaging the soil or the crops. This high-throughput and non-destructive approach allows breeders to monitor spatial and temporal variability across vast areas, providing a more efficient and less invasive way to evaluate large-scale trials compared to ground-based manual or vehicular methods.

216. (B) The intensive, multi-level characterization of an organism's traits using diverse HTP technologies
Deep phenotyping refers to the comprehensive and detailed characterization of an organism's traits across multiple levels of biological organization. This approach uses a diverse array of high-throughput technologies to capture a wide range of information, from molecular and physiological data to structural and architectural features. By integrating these multi-level measurements, deep phenotyping provides a holistic and high-resolution view of the phenome, enabling a deeper understanding of the genetic and environmental drivers of trait expression.

217. (B) It ensures that only pure canopy pixels are measured, excluding confounding background soil pixels
High spatial resolution is critical for accurate thermal phenotyping because it allows for the precise isolation of the plant canopy. In field images, pixels often contain a mix of vegetation and background soil, which has a much higher temperature. By using high-resolution sensors, researchers can segment the image to ensure that only "pure" canopy pixels are used for temperature measurements. This excludes the confounding heat from the soil, providing a more accurate reflection of the plant's true physiological status.

218. (B) It allows for the real-time data processing and trait extraction during the flight, reducing post-processing time
Edge computing involves processing data directly on the platform where it is collected, such as on a UAV. In phenomics, this allows for the real-time extraction of traits during the flight. By handling the initial data processing locally, edge computing reduces the volume of data that needs to be transferred and minimizes the time required for later post-processing. This enables faster decision-making and a more efficient workflow for large-scale field phenotyping operations.

219. (B) Phenotypic plasticity
Phenotypic plasticity is the biological principle that explains how a single genotype can express different trait values when exposed to varying environments. This capacity for flexible expression is an adaptive mechanism that allows plants to adjust their growth and development to local conditions. Plasticity ensures that the phenotype is not a fixed result of the genetic code but is a dynamic outcome of the constant interaction between genes and the surrounding environmental factors.

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220. (A) P-4, Q-2, R-1, S-3
Phenomics and genomics utilize various modeling and genetic concepts to understand trait expression. A reaction norm maps phenotypic response to an environmental gradient, while pleiotropy describes a single gene's influence on multiple traits. Phene synergism refers to the non-additive interaction of basic units to form emergent traits. Genomic selection integrates genome-wide markers and phenomic data to predict performance, providing a comprehensive framework for modern data-driven breeding and genetic research.

221. (B) A recorded variable used to statistically account for non-genetic variance during trait modeling
Environmental covariates are essential variables in the mathematical modeling of phenotypic data. By recording factors like ambient temperature, light intensity, and soil moisture

over time. This temporal and quantitative detail allows for a better understanding of the genetic control of dynamic processes, bridging the gap between genetic instructions and the final physical outcome.

207. (D) A drastic increase in false positives and false negatives
Phenotyping inaccuracy is a major problem for Genome-Wide Association Studies because it leads to statistical errors. High levels of measurement noise can obscure true genetic associations, causing false negatives. Conversely, experimental error can create spurious correlations, leading to false positives. Accurate and precise phenotyping is essential for reducing this background noise, ensuring that the identified genetic variants are truly related to the phenotype and providing a reliable map of genetic architecture.

208. (A) The transcriptome (mRNA)
The transcriptome is the foundational link that translates genomic instructions into biological reality. It consists of the complete set of RNA transcripts produced by the genome under specific conditions. By reflecting which genes are actively being expressed, the transcriptome serves as the immediate molecular bridge between the static genetic code and the functional proteome, directly influencing the subsequent developmental and physiological processes that shape the final phenome.

209. (A) Controlled greenhouse environments fail to replicate the complex GxE dynamics of real-world agricultural fields
A fundamental limitation of "plants to sensors" greenhouse platforms is the gap between controlled and natural environments. While these systems offer high precision, the simplified conditions of a greenhouse cannot capture the full complexity of multi-stress interactions and environmental variability found in the field. This limits the ability to study authentic GxE interactions, meaning that discoveries made in the greenhouse may not always translate directly to crop performance in real agricultural settings.

210. (A) Both A and R are true and R is the correct explanation of A.
High-throughput phenotyping is the solution to the phenotyping bottleneck because it fundamentally changes how traits are measured. By replacing slow, subjective, and often destructive manual methods with automated sensor-based systems, HTP allows for the rapid and objective capture of high-quality data. This scalability and precision allow researchers to evaluate large populations continuously, matching the speed of modern genomics and providing the data needed to understand gene function at scale.

211. (B) It increases the capture of genetic variation by considering the inheritance of linked alleles
Using haplotype blocks—sets of alleles that are inherited together—improves genomic-phenomic studies by accounting for genetic linkage. Instead of looking at individual SNPs in isolation, haplotypes capture the combined effect of multiple linked variants. This approach provides a more comprehensive view of genetic variation and can lead to more accurate associations with traits, as it reflects the way segments of the genome are actually passed through generations in a population.

212. (C) To provide accurate measurements used to calibrate and validate indirect sensor-based machine learning models
Ground truthing is an essential validation step in high-throughput phenomics. It involves collecting direct manual measurements of traits that are also being recorded by sensors. These "ground truth" data are then used to calibrate mathematical algorithms and to validate the accuracy of the automated trait extractions. This process ensures that the indirect measurements provided by the sensors are a reliable and accurate representation of the plant's true physical and physiological state.

213. (C) Storing, transferring, and processing terabytes of multi-dimensional image data
A primary challenge of high-throughput phenomics is the massive scale of the data generated. High-resolution sensors and continuous monitoring produce terabytes of multi-dimensional image and spectral data. Managing this "Big Data" requires significant computational infrastructure for storage, high-speed transfer, and complex processing. Overcoming these logistical and computational hurdles is essential for the successful implementation of HTP and for the effective analysis of the resulting phenotypic information.

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199. (A) Plasticity is the variable expression of the same genotype; mutation is an actual structural change to the DNA
A fundamental distinction exists between phenotypic plasticity and genetic mutation. Plasticity is a flexible response where a single genotype produces different phenotypes depending on the environmental context, without changing its underlying DNA. In contrast, a mutation is a permanent structural change to the genetic sequence itself. Understanding this difference is essential for studying adaptation and for recognizing how plants can respond to their environment both through short-term flexibility and long-term evolutionary change.

200. (A) I, II and IV
High-throughput phenotyping platforms are generally classified into two main paradigms. "Plants to sensors" is typical for automated greenhouses where potted plants move to stationary sensors. "Sensors to plants" involves mobile platforms, including ground-based vehicles and aerial UAVs, that move to stationary plants in the field. These approaches are complementary, providing detailed data across both controlled and natural settings to help researchers understand the complex relationship between genetics, the environment, and plant traits.

201. (C) Its underlying genotype
While the environment shapes the final phenotype, the underlying genotype acts as the ultimate determining boundary for an organism's range of expression. The genotype provides the genetic blueprint and sets the potential limits of the reaction norm, defining the various states the phenome can possibly take under different conditions. Although plasticity allows for flexibility, it is the genetic code that dictates the capacity and direction of an organism's response to its surroundings.

202. (D) Convolutional Neural Networks (CNN)
Convolutional Neural Networks are a specialized deep learning architecture uniquely suited for processing image data. They use a mathematical operation called convolution to identify spatial patterns and features within a grid-like structure, such as the pixels of a digital image. This capability makes CNNs exceptionally effective for automated trait extraction, allowing for the rapid and objective identification of complex characteristics like plant organs or disease lesions in high-throughput phenomic datasets.

203. (B) It improves the precision of the model training set, enhancing the ability to predict breeding values
Accurate phenotyping is critical for Genomic Selection because it improves the quality of the data used to train predictive models. High-resolution phenotypic data reduces measurement error, providing a clearer link between genetic markers and traits. This increased precision in the training set leads to more accurate predictions of the breeding values of new individuals, ultimately enhancing the efficiency and success of selection decisions in modern plant breeding programs.

204. (B) A single gene simultaneously influencing the expression of multiple, potentially unrelated, phenotypic traits
Pleiotropy is a genetic principle where one gene has multiple effects on an organism's phenotype. This occurs because the gene's product may be involved in several different biological pathways or be active in various tissues. In the context of phenomics, pleiotropy means that a single genetic variation can impact multiple phenes simultaneously. Understanding these broad effects is essential for accurately mapping the genome-to-phenome relationship and for anticipating the consequences of genetic selection.

205. (A) High-resolution terrestrial LiDAR scanning and 3D modeling
For extracting fine-scale geometric traits in the field, terrestrial LiDAR is the most effective technology. It generates dense 3D point clouds that accurately represent the physical structure of the plant. By creating detailed 3D models, researchers can precisely measure characteristics like leaf angles and stem geometry non-destructively. This provides a high level of anatomical detail that is difficult to achieve with traditional 2D imaging or lower-resolution aerial sensors.

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206. (B) By linking genetic markers with continuous, high-resolution biological trait kinetics
The integration of genomics and phenomics overcomes the limits of classical genetics by providing a much more detailed view of trait expression. By linking genetic markers with high-resolution, continuous data on plant growth and physiology, researchers can see how traits develop

during phenotyping, researchers can use statistical models to account for the portion of trait variation caused by the environment. This helps to reduce experimental noise and isolate the true genetic contribution to the observed phenotypes, improving the precision and reliability of breeding and genetic studies.

222. (A) Hyperspectral imaging
Hyperspectral imaging is uniquely powerful for pre-symptomatic stress detection because of its high spectral resolution. It captures reflectance across hundreds of narrow bands, allowing it to detect subtle changes in pigment composition and cellular structure that occur before any chlorosis or damage is visible to the human eye. This detailed spectral data provides a sensitive indicator of the plant's physiological status, enabling the identification of stress and disease at a very early stage.

223. (B) It acts as the elemental building block of function that combines to form complex emergent traits
A phene is the fundamental functional unit within the organizational hierarchy of an organism's phenome. It represents an elementary biological component, such as a specific anatomical feature or physiological process. These phenes act as the basic building blocks that combine and interact synergistically to produce the more complex emergent traits observed at the macroscopic level, such as yield and resilience, providing the foundation for biological function and performance.

224. (A) They offer near-perfect sub-millimeter spatial repeatability across temporal scans
Ground-based field gantries provide a significant advantage in spatial precision. Because they move on fixed rails, they can return to the exact same sub-millimeter coordinates for every scan throughout the season. This high level of spatial repeatability is superior to tractor-based or manual methods, allowing for the precise tracking of individual plant growth and architectural changes over time with minimal spatial error and no physical disturbance to the soil or plants.

225. (B) Maximum quantum efficiency of Photosystem II ($\frac{F_v}{F_m}$)
The $\frac{F_v}{F_m}$ ratio is a critical parameter measured by chlorophyll fluorescence to detect early stress. It indicates the maximum quantum efficiency of Photosystem II and is a sensitive marker for physiological decline. A localized drop in this value often occurs before physical symptoms like lesions appear, making it an essential metric for the pre-symptomatic detection of pathogen infections and other environmental stressors that disrupt the plant's photosynthetic machinery.

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226. (A) Controlled greenhouse environments fail to replicate the complex multi-stress interactions found in natural fields
A major hurdle in translating greenhouse findings to the field is the difference in environmental complexity. While automated greenhouses offer high precision, they provide a simplified setting that lacks the multiple and fluctuating stressors of natural agricultural fields. This means that the GxE interactions and synergistic effects observed in the greenhouse may not accurately reflect how a genotype will perform under the authentic, complex conditions of real-world crop production.

227. (B) They excel at automatically learning and extracting complex spatial features directly from unstructured image data
Convolutional Neural Networks are a primary tool in plant phenomics because they can handle large-scale image analysis with high efficiency. CNNs are designed to automatically learn the relevant spatial features and patterns directly from raw image data, such as identifying specific plant organs or disease spots. This automation overcomes the limitations of manual feature engineering, providing a fast, objective, and accurate way to extract phenotypic traits from complex and unstructured datasets.

228. (C) The specific genotype
The genotype is the foundational variable that dictates the baseline potential for an organism's entire phenome. While the environment and sensing technology influence how traits are expressed and measured, it is the underlying genetic code that provides the initial instructions and sets the limits for growth and development. The genotype serves as the fundamental starting point from which all phenotypic traits emerge through the complex processes of gene expression and interaction with the surrounding environment.

229. (B) By lowering phenotypic error variance, thereby increasing the signal-to-noise ratio needed to detect associations
Precise phenotyping via high-throughput platforms significantly improves the results of GWAS by reducing the noise in the data. By providing more accurate and repeatable trait measurements, HTP lowers the phenotypic error variance, which increases the statistical power to detect true associations between genetic markers and traits. This higher signal-to-noise ratio leads to the more reliable discovery of the genomic regions that control important agricultural and biological characteristics.

230. (B) III and V
Integrating genomic and phenomic data enhances breeding models by providing high-resolution trait information. However, this integration does not physically remove micro-environmental variations, which remain present in field conditions. Furthermore, multi-environment trials are still essential to validate performance across diverse target populations. Therefore, assertions suggesting that data integration eliminates environmental influence or the need for large-scale field testing are inaccurate, as these factors remain central to agricultural research.

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